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VEGETATIVE STABILIZATION OF MINERAL WASTE HEAPS

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Washington, DC 20460

ABSTRACT

This report reviews the establishment of vegetative cover as a candidate method for reclaiming mineral ore waste heaps. The report begins by describing the location and properties of spoils and tailings from mining and ore beneficiation, and briefly reviews present methods for controlling dust emissions from them. In the bulk of the report, fundamentals for the establishment of vegetative cover are developed and a detailed review of case histories of both successful and unsuccessful revegetation are given. The report also contains a catalog of individual plant species. From this mass of information some general guidelines for establishing vegetative cover emerge.

This report was submitted in fulfillment of Task No. 31 of EPA Contract No. 68-02-1325 by the Research Triangle Institute under the sponsorship of the Environmental Protection Agency. Work was completed as of September 1975.

VEGETATIVE STABILIZATION OF MINERAL WASTE HEAPS
(A SURVEY)

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Mr. D. K. Oestreich, EPA, who initially recognized the need for such a study and nurtured it into existence, was the EPA Project Officer. His influence and direction are reflected throughout the report.

Many members of the agricultural/agronomical community throughout the United States were consulted during the course of the report preparation. They provided suggestions and ideas, reprints and data, and perhaps most important, keen interest and encouragement. Hopefully the report captures at least a fraction of their enthusiasm for getting the job done and partially justifies the time and contributions they so generously gave in response to our requests.

1.0 CONCLUSIONS

1.1 STATE-OF-THE-ART

This report assesses the state-of-the-art in vegetative stabilization of mineral waste heaps. It is shown that a systematic approach to problem solving is lacking. Horticultural techniques are described which are generally applicable, but horticulture is as much an art as it is a science when directed at a specific reclamation problem. The report does discuss some of the recent innovations of horticulture including the use of surface binding materials which provide temporary terrain stability while vegetation is being established. The discussion of case histories in this report is analogous to an art appreciation course. An understanding of successful past approaches to specific problems provides some insight into choosing approaches for solving future problems.

The importance of plant succession is pointed out. The initial mission with regard to any waste pile is to get something to grow. As time goes on, the pioneer species will improve conditions so that other species will invade and become established.

The importance of planning is strongly emphasized. Proper stockpiling of topsoil and overburden in any mining operation will allow the eventual reclamation to be done at minimal cost and effort.

In spite of the lengthy and intensive investigations of vegetative stabilization of mineral waste heaps that have been and are being carried out by United States Government, university and industrial researchers, the problem is still too complex to permit the formulation of guaranteed revegetation procedures. In practice each new candidate site for vegetative cover must be treated as a unique problem; trial and error experimentation on test plots must precede any large scale revegetation effort, using previous experiences as general guidelines to formulate the test program.

Given enough time and resources, any mineral waste heap in the United States could be covered with vegetation; the problem is to establish a cover at a cost compatible with the value of the land before and after the reclamation. It might appear to be folly to dig up a land area for a net gain of $500/acre, if the cost of returning the land to its previous state is $5000/acre. If the $5000/acre investment can enhance the value of the land--make it worth more after mining and reclamation than before--then the high post-mining costs of the land transformation may be justified. In short, the optimum strategy to pursue in any given vegetative stabilization task, including whether to even consider or attempt a vegetative solution, depends strongly upon economic factors, thus further complicating attempts to express the problem and its solutions in complete closed form.

1.2 REGIONAL CONSIDERATIONS

A long-term interest in solving the revegetation problems of coal mining wastes in the northeastern United States has resulted in a research program which has been active and productive for many years. The major problems are with old, inactive waste heaps, which are aesthetic blights and pose serious acid drainage and filtration problems. However, air quality problems caused by waste piles in the East are minimal except in isolated cases. Consequently, EPA should assign a relatively low priority to initiating revegetations studies in the East unless a major air pollution hazard becomes evident and local ordinances and practices are not solving the problem.

Industrial mineral wastes such as fly ash may also cause serious local air pollution problems in the East.

The regions of the United States most susceptible to wind erosion, are the Great Plains and Rocky Mountains. These regions are growing in importance as sources of energy-producing minerals including coal, uranium and oil shale, and metal ores such as copper. The prevailing dry, windy climate in these areas promotes wind erosion, and dust storms are a common occurrence throughout the region (Hagen and Woodruff, 1975). Unfortunately this climate makes vegetative growth extremely difficult to establish.

Methods and procedures for revegetating mineral wastes in the West are being studied intensively by both the Bureau of Mines and the Department of Agriculture. Progress has been made, but the research is still in its infancy and the problems are severe. The trend toward increased dependence on the West for energy minerals makes development of methods for minimizing environmental insult in the West mandatory.

2.0 RECOMMENDATIONS

2.1 MINERAL WASTE HEAPS AS SOURCES OF HAZARDOUS AIR POLLUTANTS AND FUGITIVE DUST EMISSIONS

An inventory of mineral waste heaps potentially capable of emitting hazardous quantities and/or types of air pollutants should be prepared from existing records and updated periodically. Field emissions measurements of those sources identified as potentially significant should then be undertaken. The mass and composition of ambient air samples, collected in the vicinity of known or suspected hazardous mineral waste heaps such as asbestos tailings, uranium tailings, spent shale, Western coal and others, should be measured and analyzed.

The information acquired in these studies would provide answers to several important questions:

1) Is the magnitude of fugitive dust emissions from mineral waste heaps a problem for EPA to concern itself with?

2) During dust storms many sites in the West are in violation of ambient air standards for total suspended particulates. Do mineral waste heaps such as tailings or spoils make it any worse? If the tailings and spoils were stabilized, how much better would the ambient air quality be?

3) Which mineral waste heap types cause problems because of the chemical composition and size distribution of the emitted dust?

2.2 USING SOLID WASTES AS WASTE HEAP AMENDMENTS

Mineral wastes are a varied lot; often the deficiencies of one waste heap are the excesses of another. Research into applications in which fly ash, municipal sewage and other solid wastes have been used to remedy the deficiencies of acidic spoils, should be systematically undertaken.

The problem is really one of logistics--getting the right waste to the right waste heap at a net cost which is less than that which would be required to treat the two problems separately. If one can dispose of municipal solid waste or power plant fly ash and at the same time correct a compositional deficiency in a spoil, the chances for economically attractive operation are greatly enhanced.

This approach requires:

a) the preparation of a geographical inventory of solid wastes suitable for waste heap amendment;

b) research on the use of these solid wastes for revegetating mineral waste heaps or other barren areas, including the determination of the practical limitations set by transportation and handling costs.

2.3 QUANTITATIVE ASSESSMENT OF THE EFFECTIVENESS OF VEGETATIVE COVER IN SUPPRESSING THE EMISSION OF SUSPENDED PARTICULATES

No measurements of the effectiveness of vegetation in reducing the emission of suspended particulates now exist. All evaluations of vegetative cover are expressed in either qualitative agricultural terms--"good cover, grows well"--or in semiquantitative terms--"50 percent survival, 20 percent coverage." What is really needed is a direct measure of the suppression of emissions of suspended particulates. Some species may be btter than others in controlling emissions.

This activity should begin as a wind tunnel study in which soil or spoil surfaces are covered with different plant species and the wind borne particulate concentration is measured as a function of various important parameters.

3.0 INTRODUCTION

This report reviews the use of vegetation as a control method for fugitive dust emissions from man-made mineral waste heaps. Such sources are common in mining operations but can also arise in the course of carrying out other industrial activities.

Fugitive dust is a broad term used to describe any solid particles originating from any source other than an industrial smokestack, residential flue or other duct specifically constructed to control or transport emissions. The implication of the term is that these emissions have escaped from the planned process flow and, hence, constitute "fugitive" action not within the defined process or otherwise accounted for. As such, fugitive emissions accompany virtually every activity of society--from children at play in the schoolyard to grandma dusting the furniture; from the gasoline pumps at the service station to the aerosol sprays of the beauty salon. Fortunately, only a limited number of these sources are important in magnitude or composition. This report considers just one of these sources--the mineral ore waste heap, as described in Table 1.

Mineral waste heaps come into being because of mining and milling operations and, in particular, strip mine operations. What any mining operation produces is a mixture of useful ore and unwanted gangue minerals. A preliminary separation of ore from gangue is made in the vicinity of the mine mouth, the useful ore going to the mill or to market and the waste being discarded in any convenient nearby area. Once at the mill the ore is ground and further separated into useful ore and mineral waste called tailings. These finely ground tailings are often transported from the mill to storage ponds by water and have traditionally been abandoned and ignored but are currently attracting more attention because of their unsightliness and their emissions of fugitive dust.

Overburden is that material which covers a mineral deposit and which must be removed in the strip mining (surface mining) of the mineral beneath. Efficient earth moving equipment now exists that is capable of removing and shoving aside the overburden in huge volumes. The displaced

Table 1. CLASSIFICATION OF SOLID MINERAL WASTES [Miller and Collins, 1974]

	Group and Type			
	1. Overburden	2. Gangue or waste rock	3. Mine and mill tailings	4. Metallurgical, chemical, & pulp and paper residues
Description	Soil, sand, clay, shale, gravel, boulders, etc.	Rock which must be broken and removed to obtain ore; many types, e.g., limestone, granitic and volcanic rocks.	Rock minerals, usually sand to slime but sometimes larger; may include sulphides.	Slags, fly ash, cinders, dust, slimes, sludges, etc.
Characteristics	Heterogeneous and unconsolidated.	Broken rock, usually homogeneous, but varying widely in size.	Usually homogeneous and uniform in character and size.	Usually homogeneous and uniform in character and size; sometimes toxic.
Examples	Cover removed from open pit coal, gypsum, and some iron mines.	Broken rock, usually from open pits, but also from underground sources.	Tailings from many diverse operations, e.g., base, ferrous and precious metal mines, and non-metallic mineral operations.	Slags from iron and steel plants, fly ash from power plants, salt from potash recovery operations.
Nature of Problem	Materials handling and storage; little intrinsic value but may be useful as fill, ballast, and in landscaping.		Materials handling and storage; may compete for valuable land space; unsightly and possible source of air and water pollutants; potential sources of additional metals and minerals.	

and disturbed overburden, called spoils, makes up the second major source of wind blown fugitive emissions from waste heaps of mineral ores. The fragment size of overburden tends to be much larger than that of tailings from beneficiation and milling and hence somewhat less subject to wind erosion.

Tailings and overburden spoils are the two primary types of mineral waste heaps to be discussed in this report. Other significant sources can exist such as storage piles for raw feedstock or ores themselves in transit on open railway cars. Because of their temporary status such sources generally are not suitable for control via vegetative cover. One exception is the long term, open storage of low grade flotation concentrates (e.g., zinc) which is practical when prices are depressed. Control methods that work on these temporary sources can sometimes be used to provide temporary protection for the waste heaps of interest--perhaps as an interim control method while vegetation is getting started. Consequently, even these temporary sources will not be totally ignored.

As the preceding discussion implies, the emphasis will be on controlling fugitive emissions from man-made mineral waste heaps. Certain natural terrains, however, merit attention also, not necessarily because of their contributions to air emissions but because of their similarity in composition and properties to man-made mineral wastes. Understanding the vegetative cycles and ecology of certain of these natural soils, such as salt water beaches or lava fields, can provide insights that might lead to better methods of vegetative cover in general.

The mineral waste heap problem is national in scope; heaps exist in every state. While air emissions attributable to mineral waste heaps as a whole do not dominate the fugitive emissions class, being not nearly so large as those from many other sources of fugitive emissions (for example, dirt roads, agricultural activities or construction), they often dominate the air quality in their immediate vicinity--especially under certain weather conditions. In addition, the toxic substances characteristic of some mineral wastes makes adequate control much more important than would be justified on a mass emission basis alone. As a result, methods for controlling mineral waste pile emissions are becoming important. This report reviews control methods for fugitive emissions from mineral waste heaps, emphasizing the vegetative cover method as the longest term, most appealing solution, although not always the least expensive on an initial cost basis.

This report covers five separate topics, all of which can be read independently in that each section is self-contained. The section arrangement, however, does reflect a logical sequence, proceeding from the problem definition (Section 4, Sources) and existing solutions (Section 5) on through a discussion of the important factors to consider in growing vegetative cover on mineral waste heaps (Section 6) and a detailed review of previous and ongoing attempts to put vegetative cover principles into practice (Section 7, Case Studies). The Conclusions (Section 1) and Recommendations (Section 2) summarize the status of the vegetative cover approach to controlling fugitive dust emissions from mineral ore waste heaps and make both general and specific recommendations for studies that would enhance EPA's ability to capitalize on the vast research already underway.

The International System of Units (SI) (Mechthy, 1969) units are used throughout with the more familiar units generally being added in parenthesis. For some plots or equations, the SI units are inserted parenthetically in order to preserve the constants or scales originally used.

BASIC SI UNITS

Quantity	Name	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Temperature	kelvin	K
Electric Current	ampere	A

DERIVED SI UNITS

Quantity	Name	Symbol
Area	square meter	m^2
Volume	cubic meter	m^3
Density	kilogram/meter^3	kg/m^3
Force	newton	N $(kg \cdot m/s^2)$
Pressure	newton per square meter	N/m^2
Work, energy	joule	J
Power	watt	W (J/s)

PREFIXES

Factor By Which Unit Is Multiplied	Prefix	Symbol
10^{12}	tera	T
10^9	giga	G
10^6	mega	M
10^3	kilo	k
10^2	hecto	h
10	deka	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

4.0 U.S. SOURCES OF MINERAL ORE WASTES

Mineral wastes in the U.S. amount to about 1.5 Tkg (1.7 billion tons) annually with the total accumulated mineral solid wastes now approaching 22.7 Tkg (25 billion tons), covering 8.1 Gm^2 (2 million acres) of land (Dean and Havens, 1973). Mineral wastes are second only to agricultural wastes in magnitude and represent nearly 40 percent of the annual solid wastes produced in the U.S.

The most serious impact upon air quality comes from those waste piles occurring in arid or semi-arid regions such as the Plains of the U.S. (see Figure 1). The dry climate in combination with the presence of high surface winds unobstructed by trees or other barriers combine to make such regions "dust bowls" with serious consequences. Mining in these regions is of increasing importance so that the number and size of mineral waste piles in this vulnerable, wind-erosion prone region of the U.S. seems certain to increase. The trend is to open pit or strip mining because of the higher costs of underground mining. Surface mining inherently offers more potential for fugitive emissions.

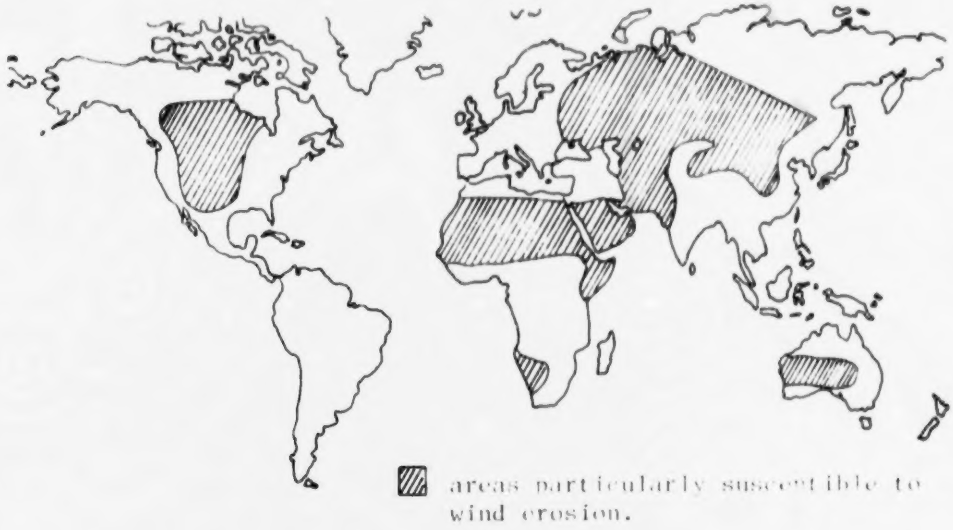


Figure 1. World-wide wind erosion [Hudson, 1971].

This section identifies a number of these mineral waste piles of concern and presents some of their properties.

4.1 PROPERTIES OF SPOILS/SOILS

Properties of spoils/soils that are both useful in planning revegetation strategy and relatively easy to measure with adequate accuracy and precision are discussed in this section. The discussion includes both chemical and physical properties and a brief description of how the property is measured.

4.1.1 Chemical Composition

Chemical composition is one of the most important properties of a spoil. Composition, as determined by wet chemical analysis, helps to determine whether the spoil will support vegetative growth as is or requires additional nutrients; and whether or not the concentration of certain elements is sufficiently high to be toxic. Organic matter and microorganisms are important for vegetation; their absence is a major difference between a spoil and a spoil. Agricultural soil cannot be adequately described in terms of its inorganic composition and cannot adequately be synthesized in the laboratory because not all significant properties are yet known.

What is generally agreed upon is that 16 chemical elements are essential for plant growth (Table 2).

Table 2. ELEMENTS ESSENTIAL FOR PLANT GROWTH
[Schellie and Rogier, 1963]

Boron
Calcium
Carbon
Chlorine
Copper
Hydrogen
Iron
Magnesium
Manganese
Molybdenum
Nitrogen
Oxygen
Phosphorus
Potassium
Sulfur
Zinc

Of these essential sixteen, three--carbon, hydrogen and oxygen--are supplied directly by the surrounding air and water. The other thirteen must come from the soil.

Elements used by plants in relatively large amounts are the macronutrients--nitrogen, phosphorus, potassium and calcium in addition to carbon, hydrogen and oxygen. The remaining essential elements are the micronutrients--those required in only trace quantities. Both macro-and micronutrients are essential.

In most soils and spoils, nitrogen, phosphorus, potassium and occasionally calcium and magnesium are inadequate or depleted by use. Replacing these elements is the primary function of fertilizer.

The trace elements are not usually deficient. Indeed a more common problem is their excess. What really is required is not just the presence of a particular element but its presence in the right concentration range. Too little constitutes a mineral deficiency but too much can be equally undesirable and cause a soil toxicity. Further complicating a specification, however, is that the elements interact with each other so that the optimum concentration range for one element depends upon the concentration of another essential element or even of a non-essential element--phosphorus at 40 ppm is beneficial when calcium is high (64 ppm) but toxic when calcium is low (8 ppm); trace strontium is beneficial only when calcium is low etc. (Treshown, 1970).

Having elements present in the soil in a certain concentration range is still not the same as having them available to the plant life. Solubility of the chemical compounds present plays a major role in determining available plant nutrients or, conversely, the presence of phytotoxicants. Soil pH is thus a primary, although indirect, measure of nutrient availability and soil toxicity. Figure 2 illustrates the relationship for alumina and silica, the two most abundant oxides in the earth's crust (Table 3). Similar dependencies hold for other compounds, some of which (chiefly heavy metal salts) are very soluble in low pH soils. The solubility of heavy metals is what makes soils of low pH toxic rather than any reaction between the H^+ ion and the plant itself.

Table 3. APPROXIMATE CHEMICAL COMPOSITION OF IGNEOUS ROCK

By elements		By oxides		By minerals	
Element	Percent composition	Oxide	Percent composition	Mineral	Percent composition
O	47.29	SiO_2	59.8 (acid)	Feldspar (silicate)	59.2
Si	28.02	Al_2O_3	17.0 (amphoteric)	Quartz (oxide)	20.4
Al	7.96	Fe_2O_3	2.6 (amphoteric)	Ferro-mag. (silicate)	9.3
Fe	4.56	FeO	3.5 (base)	Mica (silicate)	7.7
Ca	3.47	CaO	4.8 (base)	Misc.	3.3
Mg	2.29	MgO	3.8 (base)		
Na	2.50	Na_2O	3.4 (base)		
K	2.47	K_2O	3.0 (base)		
H	0.16	H_2O	1.9 (neutral)		
Ti	0.46				
C	0.13				
P	0.13				

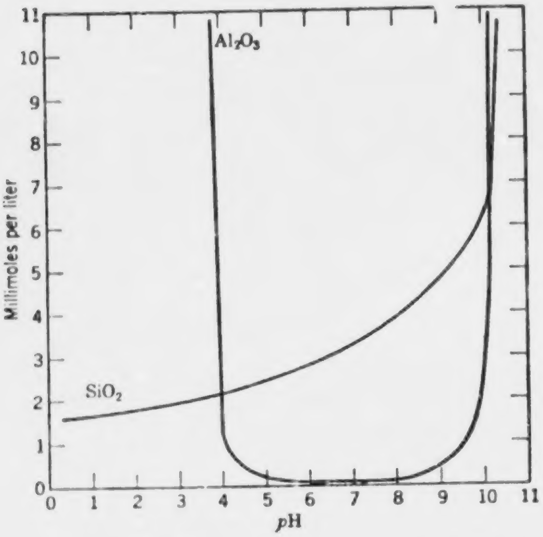


Figure 2. The solubility of silica and alumina as a function of pH. [Mason, 1966].

A third property of interest is the availability of water soluble salts in the soil such as those of sodium or calcium. The concentration of soluble salts is measured in a conductivity cell. Values of conductivity below 10 mmho/cm are preferred for vegetative growth. Above 16 mmho/cm only a very few salt-tolerant plants survive; below 2 mmho/cm, even the most salt sensitive plants thrive. Any value in excess of 4 mmho/cm limits the choice of vegetative species which will grow.

The detrimental property of excess salt in the soil results from the reduced availability of water to the plants. The saline soil holds the water so tightly (increases the osmotic pressure) that the plant cannot absorb it. (In heavily saline soils, the osmotic gradient can actually be reversed so that the soil absorbs water from the plant, a condition incompatible with plant health).

A saline soil can also be alkaline if the dissolved salt is largely a sodium salt. The percentage of the cation exchange capacity (CEC) attributable to sodium is a measure of its alkalinity. When sodium accounts for more than 15 percent of the total cation exchange capacity, the soil is alkaline.

Soils can be alkaline, saline or both. The soil is alkaline when the sodium present is excessive; it is saline when the total salts, as measured by conductivity, are excessive. The conventional measurements of importance in describing the chemical status of the soil are pH, conductivity and CEC in addition to compositional analysis by element or compound.

4.1.2 Physical Properties

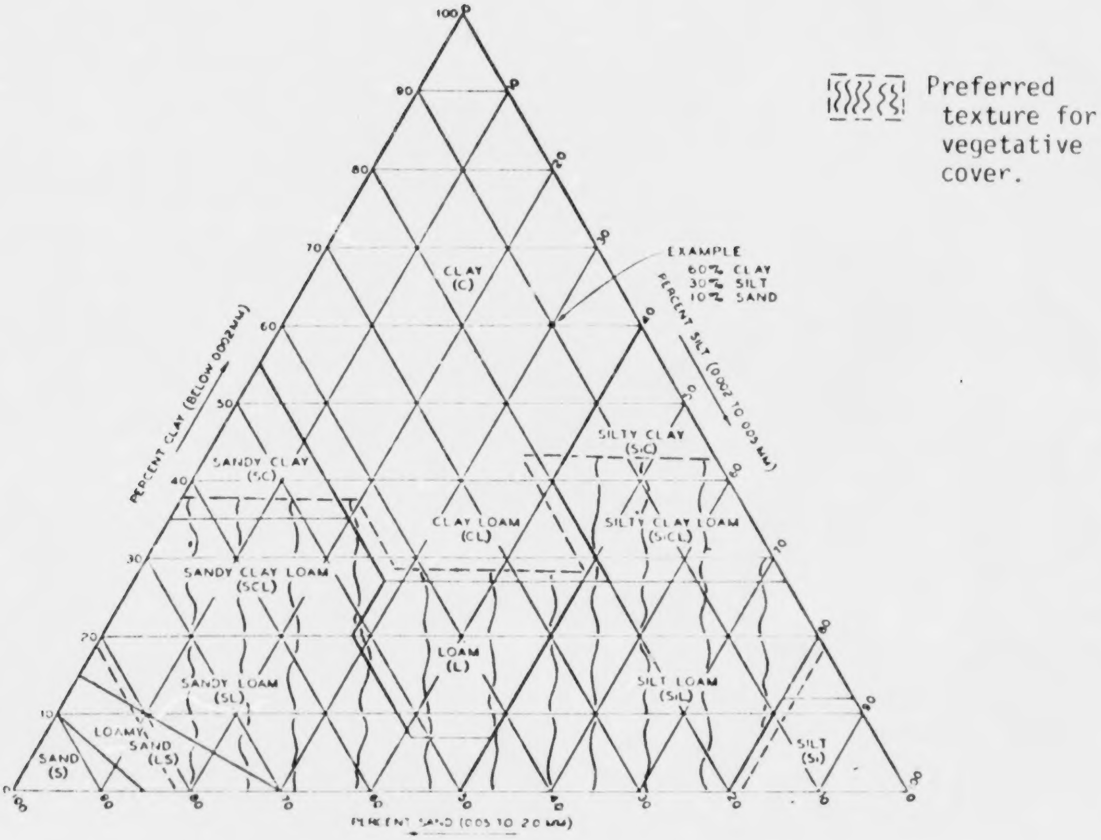
Physical properties include color, size and weight, but the most important physical property is texture. The U.S.D.A. classifies soil particles according to size as shown in Figures 3 and 4. Consequently, any given soil may be described in terms of its component particle sizes. A soil sample is dried and weighed and then sorted according to size through appropriate sieves.* Knowing the total weight in each particle size range enables one to calculate the fractional percentage of each size range and hence classify the soil in the triangle of Figure 3.

The preferred texture for agricultural soils is in the interior of the classification triangle--the loams and near loams as indicated by the shaded region of the U.S.D.A triangle. Spoils frequently contain large cobbles or boulders which only after lengthy physical and/or chemical weathering become cracked and broken into useful agricultural sized particles. Any sorting during overburden removal that permits the large cobbles and boulders to be buried will be beneficial to subsequent vegetation efforts.

4.1.3 Biological Properties

The previous paragraphs discussing physical and chemical properties state, explicitly or implicitly, some of the differences between a spoil and a soil; chemically, the spoil is likely to contain more constituents that are soluble such as the alkali salts; physically, the texture of spoil is likely to be coarser than that of soil. These differences do not loom large or formidable. It is only when comparing the biological properties that the differences become gross. Soils have large, active microbial communities; spoils initially have none.

*Agricultural laboratories of most states and various U.S.D.A. facilities will perform this service. (See Appendix C).

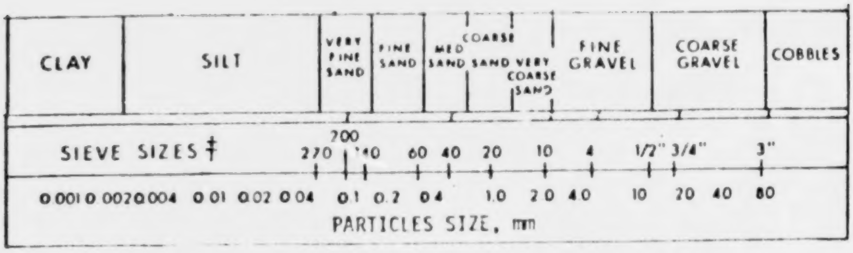

CLAY (C)
EXAMPLE 60% CLAY 30% SILT 10% SAND
PERCENT CLAY (BELOW 0.002 MM)
PERCENT SILT (0.002 TO 0.05 MM)
SILTY CLAY (SiC)
SANDY CLAY (SC)
CLAY LOAM (CL)
SILTY CLAY LOAM (SiCL)
SANDY CLAY LOAM (SCL)
LOAM (L)
SANDY LOAM (SL)
SILT LOAM (SiL)
LOAMY SAND (LS)
SAND (S)
SILT (Si)
PERCENT SAND (0.05 TO 2.0 MM)
100
90
80
70
60
50
40
30
20
10
0

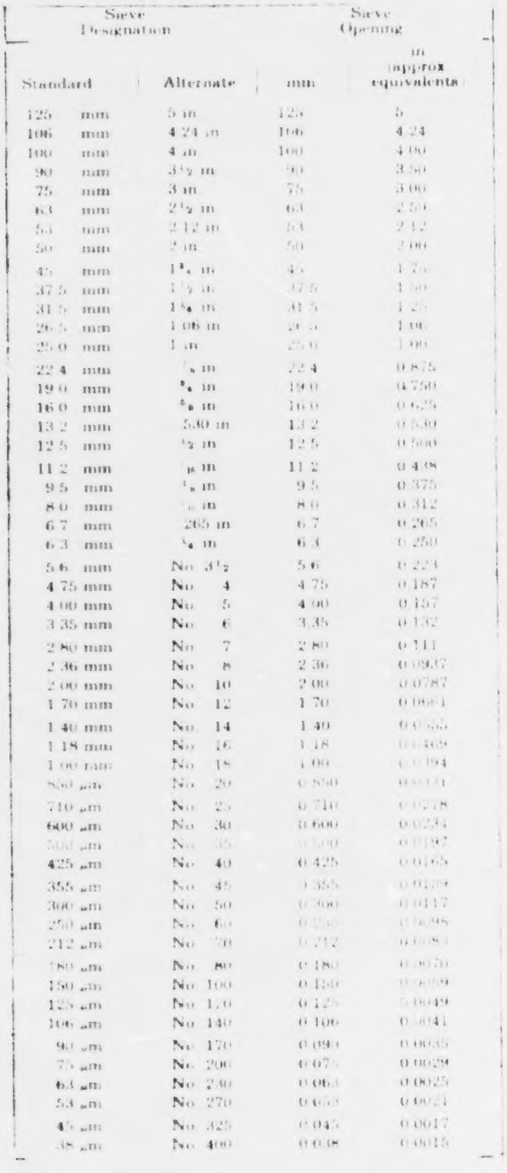
▨ Preferred texture for vegetative cover.

Figure 3. USDA Classification of Soil Textures [Needleman and Molineaux, 1969].

The reason for this difference is not hard to understand. Figure 5 shows a hypothetical soil profile illustrating the different geological soil horizons or strata. The A_1 horizon contains organic matter being decomposed by bacterial and other biological (such as earthworms) action. These processes, while not fully understood, are known to be necessary for

USDA CLASSIFICATION



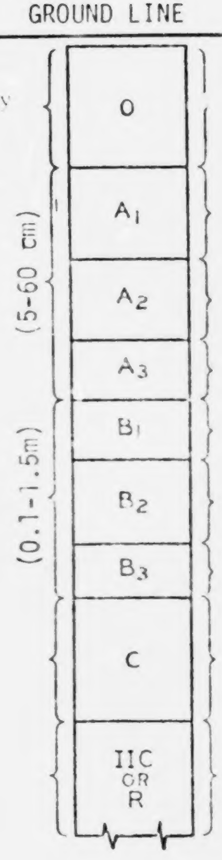


Sieve Designation		Sieve Opening	
Standard	Alternate	mm	in (approx equivalents)
125 mm	5 in	125	5
106 mm	4.24 in	106	4.24
100 mm	4 in	100	4.00
90 mm	3½ in	90	3.50
75 mm	3 in	75	3.00
63 mm	2½ in	63	2.50
53 mm	2.12 in	53	2.12
50 mm	2 in	50	2.00
45 mm	1¾ in	45	1.75
37.5 mm	1½ in	37.5	1.50
31.5 mm	1¼ in	31.5	1.25
26.5 mm	1.06 in	26.5	1.06
25.0 mm	1 in	25.0	1.00
22.4 mm	⅞ in	22.4	0.875
19.0 mm	¾ in	19.0	0.750
16.0 mm	⅝ in	16.0	0.625
13.2 mm	.530 in	13.2	0.530
12.5 mm	½ in	12.5	0.500
11.2 mm	7/16 in	11.2	0.438
9.5 mm	⅜ in	9.5	0.375
8.0 mm	5/16 in	8.0	0.312
6.7 mm	.265 in	6.7	0.265
6.3 mm	¼ in	6.3	0.250
5.6 mm	No. 3½	5.6	0.223
4.75 mm	No. 4	4.75	0.187
4.00 mm	No. 5	4.00	0.157
3.35 mm	No. 6	3.35	0.132
2.80 mm	No. 7	2.80	0.111
2.36 mm	No. 8	2.36	0.0937
2.00 mm	No. 10	2.00	0.0787
1.70 mm	No. 12	1.70	0.0661
1.40 mm	No. 14	1.40	0.0555
1.18 mm	No. 16	1.18	0.0469
1.00 mm	No. 18	1.00	0.0394
850 µm	No. 20	0.850	0.0331
710 µm	No. 25	0.710	0.0278
600 µm	No. 30	0.600	0.0234
500 µm	No. 35	0.500	0.0197
425 µm	No. 40	0.425	0.0165
355 µm	No. 45	0.355	0.0139
300 µm	No. 50	0.300	0.0117
250 µm	No. 60	0.250	0.0098
212 µm	No. 70	0.212	0.0083
180 µm	No. 80	0.180	0.0070
150 µm	No. 100	0.150	0.0059
125 µm	No. 120	0.125	0.0049
106 µm	No. 140	0.106	0.0041
90 µm	No. 170	0.090	0.0035
75 µm	No. 200	0.075	0.0029
63 µm	No. 230	0.063	0.0025
53 µm	No. 270	0.053	0.0021
45 µm	No. 325	0.045	0.0017
38 µm	No. 400	0.038	0.0015

‡ Sieve sizes are given in the numerical system of the Standard Screen Scale from 270 to 4 and in terms of the sieve opening above 0.25 in.

Figure 4. Particle Sizing Systems [Tyler Specification Tables, 1973].

GROUND LINE



Organic debris lodged on the soil; usually absent on soils developed by grasses.	O	Litter, leaf mold and humus
The Solum- This portion of the profile includes the true soil developed by the soil building processes: A-Horizon-Zone of eluviation percolating waters tend to leach out salts and fine soil particles from this horizon. (5-60 cm)	A_1	A dark-colored horizon, relatively higher in organic matter, but mixed with mineral material; very thin in spodosols, thick in mollisols.
	A_2	A light-colored horizon, representing the region of maximum leaching (or reduction). Absent in mollisols and aridisols and some other soils.
	A_3	Transitional to B but more like A than B. Sometimes absent
B-Horizon-Zone illuviation and fine particles leached from the A horizon are deposited in the B horizon. (0.1-1.5m)	B_1	Transitional to B but more like B than A. Sometimes absent.
	B_2	A deeper-colored horizon representing the region of maximum illuviation. The orstein has a definite structural behavior.
	B_3	Transitional to C.
C-Horizon-The unweathered parent soil material.	C	Substratum
IIC or R-Horizon-Any stratum occurring underneath the soil, such as hard rock, or contrasting materials that is not related to the parent material but which may have significance to the overlying soil.	IIC OR R	Underlying stratum

NOTE: Main horizons may be conveniently subdivided by using extra numerals. Thus A_{21} and A_{22} represent subhorizons within A_2.

Figure 5. Hypothetical soil profile [Hudson, 1971].

vegetative growth. They are confined to the A horizon which represents the topsoil of the profile. When the surface mining operation overturns the profile, burying the A horizon and bringing B or C strata to the surface, the microorganisms are buried. Fortunately microorganisms will reappear without human action, but the rate at which this occurs may penalize initial revegetative efforts.

One obvious solution is to carry out the surface mining operation so that the original topsoil becomes the surface soil of the spoil. Should the logistics of such a plan prove formidably uneconomic, then some plan to rapidly build up the microbial populations within the spoil (such as innoculating the seed and plantings) should be adapted.

In characterizing any spoil/soil, organic content is an essential measure.

4.2 U.S. MINING OPERATIONS OF CONCERN

Tailings and overburden spoils associated with surface mining are the two chief sources of mineral waste heaps in the U.S. In this section the major mining operations producing such waste heaps will be identified and the general properties of the waste heaps will be described. Considerable differences exist within a given industry with regard to properties of both tailings and spoils. The problem is not only that mineral composition changes from location to location, but also that waste heap structure depends on the construction technique. Given the same soil profile of overburden, different operators will most likely produce waste heaps that will differ substantially in their suitability for revegetation.

4.2.1 U.S. Mining Operations In General

As measured by production quantities the largest mining operations in the U.S. are 1) stone, 2) sand and gravel, and 3) coal. The first two of these mining operations take place in all states; the third, in many states as mapped in Figure 6. Other lower volume mining activities such as asbestos may still warrant special attention because of the recognized health hazard associated with their emissions.

For metals production, iron, copper, zinc and bauxite dominate on a mass basis. Production figures alone do not identify the sources of

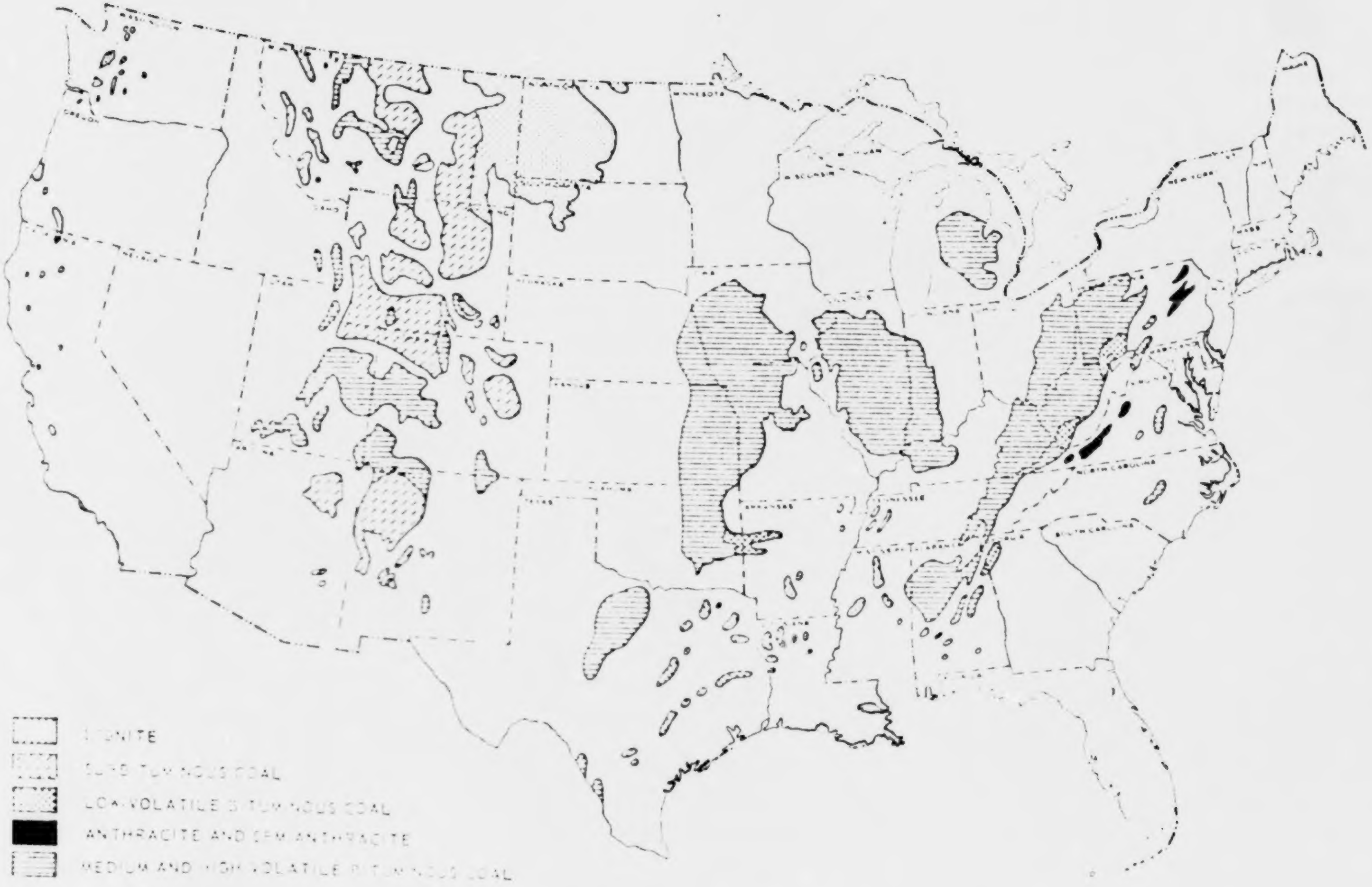

LIGNITE
SUBBITUMINOUS COAL
LOW-VOLATILE BITUMINOUS COAL
ANTHRACITE AND SEMIANTHRACITE
MEDIUM AND HIGH-VOLATILE BITUMINOUS COAL

Figure 6. Coal fields of the U.S.

Reproduced from best available copy.

mineral waste. Sand and gravel operations, for example, produce little in the way of mineral waste heaps. The U.S. Bureau of Mines estimates that anthracite and bituminous coal refuse and the wastes produced by processing the ores of copper, iron, lead-zinc, aluminum and phosphate rock account for about 80 percent of the solid waste accumulations in the U.S. (MacCartney and White, 1969).

This section gives detailed discussion of those operations, thought to make up the major sources of mineral ore waste heaps. Tables 4 and 5 summarize major sources of mineral wastes from mining and industrial activities respectively.

4.2.2 Coal Mining

Two types of coal mining make up present practice: 1) deep mining and 2) surface strip mining. Surface mining, being more economical and safer, is growing and replacing the deep mining which is far more labor intensive.

Both types of mining produce waste heaps. Deep mining operations result in the extraction of coal and other materials which are then separated into useful product (the coal) and the waste. Historically the waste consists of fine coal and particles which are slurried into storage ponds and embankments called culms. The larger waste material is piled in heaps called refuse. The refuse and culm piles are analogous to the tailings of a mineral beneficiation process.

In strip mining similar sources of mineral waste exist as with deep mining. In addition, however, the need to remove a sizable overburden layer means that another significant source of waste exists--the spoil pile. Spoils most generally exist in the vicinity of the mining operation itself. The refuse and culm piles may be more remote to the actual mining area, depending on the relative location of the milling or beneficiation plant. The overburden spoil is often simply removed from the coal bed and heaped to one side.

4.2.2.1 Refuse and Culm (Deep Mining) -- Refuse banks in the anthracite region of Northeast Pennsylvania have a long history. Some have been accumulating for over 100 years. Methods for separating coal from the intermixed rock, slate or "bone" have improved over the years so that contemporary refuse will have little useable coal (less than 5 percent of commercially saleable coal) unlike refuse from the 1800's which could

Table 4. INVENTORY OF MINERAL WASTE RESOURCES [Miller and Collins, 1974].

WASTE	SOURCE	LOCATION	PHYSICAL STATE	ANNUAL QUANTITY million tons (Tg)	ACCUMULATED QUANTITY million tons (Tg)	CURRENT OR POTENTIAL USES
Anthracite Coal Refuse	Anthracite mines	Northeastern Pennsylvania	Coarse and fine particles	10 (9)	1,000 (900)	Anti-skid material, highway aggregate
Bituminous Coal Refuse	Bituminous coal mines	Appalachia, Midwestern States	Coarse and fine particles	100 (90)	2,000 (1800)	Highway aggregate
Chrysotile or Asbestos tailings	Asbestos mines	California, Vermont Arizona	Coarse fibers	1 (0.9)	10 (9)	Additive to highway mixtures
Copper Tailings	Copper mines	Southwestern States, Michigan	Slurry or dust	200 (180)	8,000 (7300)	Fill material
Dredge Spoil	Dredging operations	Navigable waterways	Slurry	300-400 (270-360)	N.A.	Disposal, fill material
Feldspar Tailings	Feldspar mines	Northwestern North Carolina	Coarse and fine particles	0.25-0.50 (0.23-0.46)	5 (4.5)	Highway aggregate
Gold Mining Waste	Gold mines	California, South Dakota, Utah, Nevada, Arizona	Wet sand or gravel	5-10 (4.5-9)	100 (90)	Sand-lime brick
Iron Ore Tailings	Iron mines	Alabama, New York, Pennsylvania	Slurry, fine particles	20-25 (18-23)	800 (730)	None
Lead Tailings	Lead mines	Missouri, Idaho, Utah, Colorado	Slurry, fine particles	10-20 (9-18)	200 (180)	Railroad ballast, road stone
Nickel Tailings	Nickel mines	Southwestern Oregon	Fine particles	N.A.	N.A.	None

Table 4 (cont'd)

WASTE	SOURCE	LOCATION	PHYSICAL STATE	ANNUAL QUANTITY million (Tg) tons	ACCUMULATED QUANTITY million (Tg) tons	CURRENT OR POTENTIAL USES
Phosphate Slag	Phosphate smelters	Idaho, Montana Wyoming, Utah	Fine stone chips	4 (3.6)	N.A.	Lightweight aggregate, highway aggregate
Slate Mining Waste	Slate mines	New England, Eastern U.S.	Coarse particles	N.A.	N.A.	Highway aggregate
Taconite Tailings	Taconite mines	Minnesota, Michigan	Slurry, fine particles	150-200 (140-180)	4,000 (3600)	Formed block, highway aggregate
Zinc Tailings and Smelter Waste	Zinc mines and smelters	Tennessee, Oklahoma	Slurry, fine particles	10-20 (9-18)	200 (180)	Highway aggregate

Table 5. INVENTORY OF INDUSTRIAL WASTE RESOURCES [Miller and Collins, 1974].

WASTE MATERIAL	SOURCE	LOCATION	PHYSICAL STATE	ANNUAL QUANTITY million tons (Tg)	ACCUMULATED QUANTITY million tons (Tg)	CURRENT OR POTENTIAL USES
Alumina Red and Brown Muds	Alumina processing plants	Alabama, Arkansas, Louisiana, Texas	Slurry and dried fines	5-6 (4.5-5.4)	50 (45)	Insulation, pigment soil conditioner, concrete additive.
Phosphate Slimes	Phosphate processing plants	Florida, Tennessee	Slurry	20 (18)	400 (360)	Lightweight aggregate brick, pipe
Sulfate Sludges	Chemical and power plants	Distributed Nationally	Slurry	5-10 (4.5-9)	N.A.	Road base composition mixtures
Fly Ash	Coal burning power plants	Appalachia Great Lakes	Dust	32 (29)	200-300 (180-270)	Fill, lightweight aggregate, road base compositions, cement replacement
Bottom Ash	Coal burning power plants	Appalachia Great Lakes	Fine sand	10 (9)	50-100 (45-90)	Fill, lightweight aggregate, road base compositions
Boiler Slag	Coal burning power plants	Appalachia Great Lakes	Black gravel size particles	5 (4.5)	25-50 (23-45)	Fill, highway aggregate, anti-skid material, roofing granules
Blast Furnace Slag	Iron and steel production plants	Pennsylvania, Ohio, Illinois and Michigan	Coarse particles	30 (27)	N.A.	Construction aggregate, railroad ballast, fill material
Steel Slag	Iron and steel production plants	Same States as Blast Furnace Slag	Coarse particles	10-15 (9-14)	N.A.	Construction aggregate, railroad ballast, fill material
Foundry Wastes	Iron Foundries	Same States as Steel Slag	Fine Dust	20 (18)	N.A.	Pigments, colorants, highway aggregate

consist of as much as 75 percent saleable coal(MacCartney and White, 1969). Many old refuse banks have been reprocessed now in order to reclaim this product.

Anthracite refuse banks dotting the landscape in Pennsylvania exceed 800 in number, occupy over 40 Mm^2 (10,000 acres) and consist of nearly 1 Gm^3 (1 billion yd^3) of foreboding, black, coal-like material. They vary in age and composition; many are located within city limits and some are burning. Those that are on fire often burn for decades; some contemporary piles have been burning for over 50 years.

Anthracite refuse piles consist of dark to black highly pyritic, carbonaceous shales, slates, siltstones and coal fragments. The pH is highly acidic, varying between 2.7 and 4.0 The refuse has low nutrient levels, negligible organic matter and consists of about 25 percent soil-sized particles (particles less than 2 mm in diameter) (Czapowskyj, Mikulecky and Sowa, 1969). Typical properties of anthracite refuse are summarized in Table 6.

Bituminous refuse from underground mine operations displays similar properties. Texturewise, most refuse piles have in excess of 20 percent soil-sized particles, generally considered to be the minimum required for plant life (Figure 7). Chemically, however, the refuse pile is generally unfavorable for vegetation, being acidic and deficient in essential plant nutrients (Davidson, 1974).

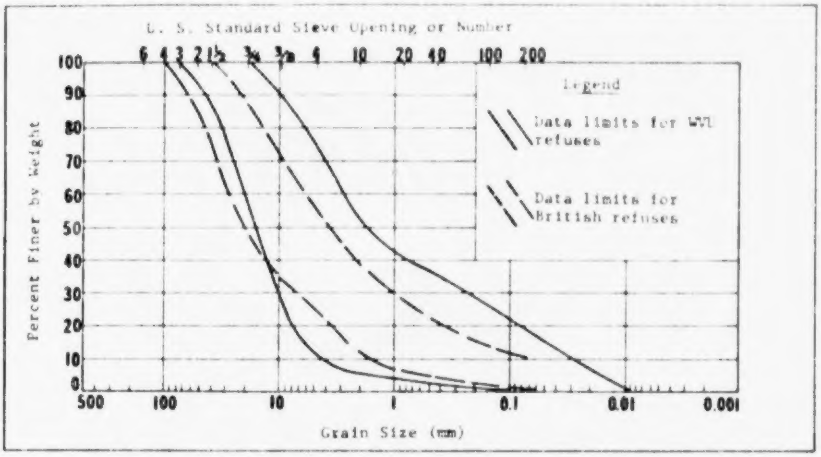


Figure 7. Particle size distribution curves for coal refuse samples [Moulton et.al., 1974].

Table 6. PROPERTIES OF ANTHRACITE REFUSE [Spicer and Luckie, 1970].

By Oxides	
	% Range
SiO_2	50-57
Al_2O_3	30-37
Fe_2O_3	3-10
TiO_2	1-2
CaO	1-2
MgO	1-2
$K_2O + Na_2O$	1-3
SO_3	0-1
By Minerals	
	% Range
Kaolinite	70
Illite	1-10
Gypsum	1-10
Quartz	1-20
Calcite	1-10
Pyrite	1-10
Rutile	1-10
--	--
By Size	
	%
10" x 2"	28.63
2" x 1"	26.16
1" x 1/2"	13.73
1/2" x 1/4"	8.68
1/4" x 8M	8.36
8M x 20M	8.48
20M x 0	5.96
--	--

2"x1" means that fraction which passes a 2" sieve but is retained on a 1" sieve.

M = Sieve Designation (see Figure 4).

Although gradually diminishing in growth, these refuse banks from underground mining are among the most inhospitable waste heaps for revegetation (or use of any kind). Anthracite refuse is confined to the northeastern area of Pennsylvania and hence is primarily a problem of that locale.

4.2.2.2 Surface Mining Spoils -- The major mode of coal mining today is strip mining which takes place over a much broader area than the deep mining operations of Pennsylvania and West Virginia. Surface mining of coal takes place chiefly in Ohio, Illinois, Kentucky and, more recently the Great Plains of the West (Figure 6). Not surprisingly, the varied locations and geology of the surface coal mining regions implies a variation in spoil properties.

Eastern surface mine spoils are typically highly acidic, regardless of type of coal being surface mined. Western spoils tend to be alkaline. Common problems are : 1) low content of organic matter and nitrogen; 2) low phosphorus levels; 3) poor moisture retention; 4) toxic concentrations of elements; 5) non-optimum texture and 6) excess soluble salts.

Chemical analysis of spoil banks show that the Wyoming and Montana spoils have high pH; most of the Pennsylvania and West Virginia spoils are strongly acidic. Soluble salts are variable but generally do present a problem. (Any value in excess of 4 mmho/cm limits the choice of vegetative species). Texture of the spoils is generally not a limitation and the color is more buff or soil-like than the black refuse from deep mining or coal beneficiation process.

4.2.3 Asbestos Wastes

Fugitive asbestos emissions can originate with:

1) Ore storage piles
2) Mill tailings
3) Product manufacturing waste dumps

The first two sources are of less importance than the third because asbestos mining is a minor industry in the U.S. when measured in terms of production quantities.

Of the nine U.S. mines operational in 1972, all but three were planning to close by the end of 1975 because of environmental restrictions.* These three remaining mines are remotely located in California, Arizona and Vermont and hence constitute low priority sources. The U.S. has always been a large importer of asbestos, chiefly from Canada; current trends are certain to reinforce this dependence.

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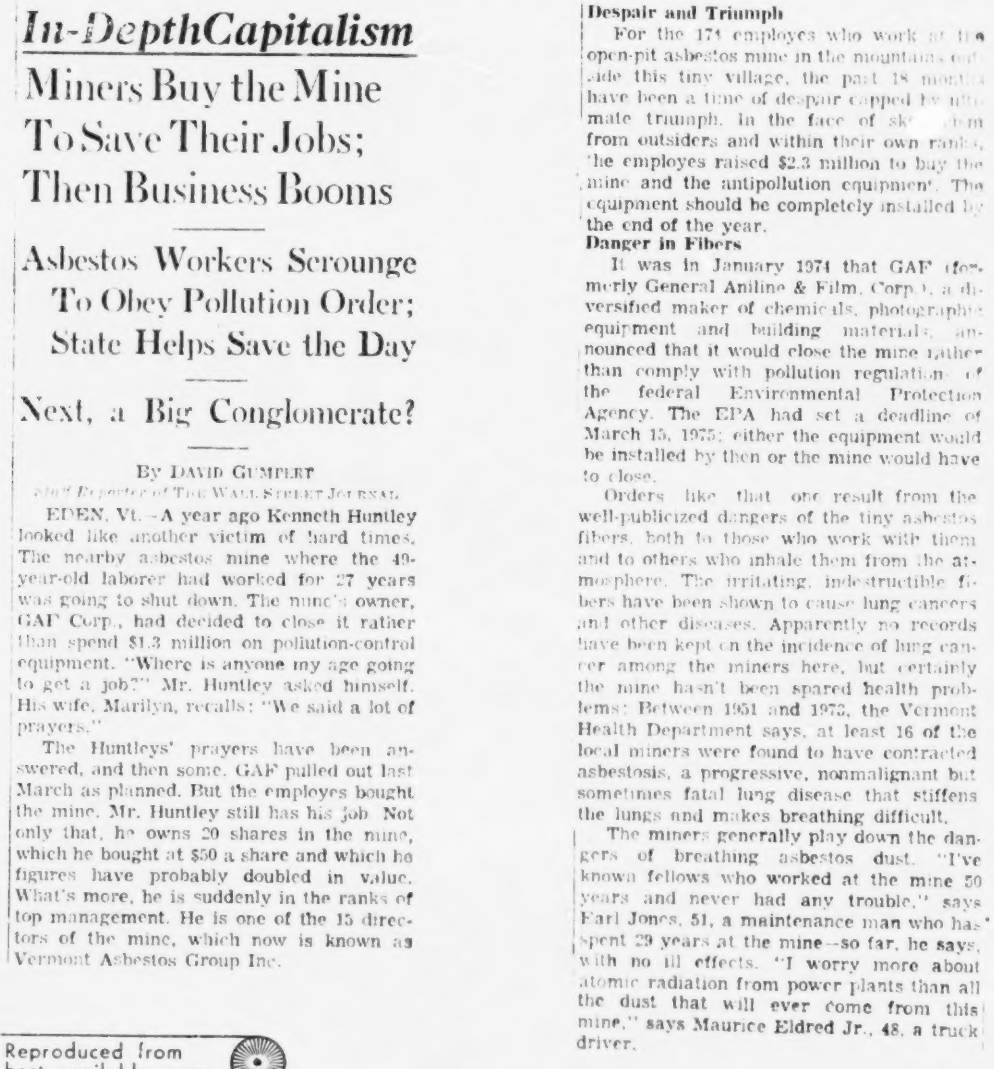
*A refreshing twist to this unhappy story occurred in Vermont where the employees themselves organized to revive the mining operation after management had given up:

(from the Wall Street Journal, Monday, August 25, 1975)



In-Depth Capitalism

Miners Buy the Mine To Save Their Jobs; Then Business Booms

Asbestos Workers Scrounge To Obey Pollution Order; State Helps Save the Day

Next, a Big Conglomerate?

By DAVID GUMPERT
Staff Reporter of THE WALL STREET JOURNAL

EDEN, Vt.—A year ago Kenneth Huntley looked like another victim of hard times. The nearby asbestos mine where the 49-year-old laborer had worked for 27 years was going to shut down. The mine's owner, GAF Corp., had decided to close it rather than spend $1.3 million on pollution-control equipment. "Where is anyone my age going to get a job?" Mr. Huntley asked himself. His wife, Marilyn, recalls: "We said a lot of prayers."

The Huntleys' prayers have been answered, and then some. GAF pulled out last March as planned. But the employes bought the mine. Mr. Huntley still has his job. Not only that, he owns 20 shares in the mine, which he bought at $50 a share and which he figures have probably doubled in value. What's more, he is suddenly in the ranks of top management. He is one of the 15 directors of the mine, which now is known as Vermont Asbestos Group Inc.

Despair and Triumph

For the 174 employes who work at the open-pit asbestos mine in the mountains outside this tiny village, the past 18 months have been a time of despair capped by ultimate triumph. In the face of skepticism from outsiders and within their own ranks, the employes raised $2.3 million to buy the mine and the antipollution equipment. The equipment should be completely installed by the end of the year.

Danger in Fibers

It was in January 1974 that GAF (formerly General Aniline & Film Corp.), a diversified maker of chemicals, photographic equipment and building materials, announced that it would close the mine rather than comply with pollution regulations of the federal Environmental Protection Agency. The EPA had set a deadline of March 15, 1975: either the equipment would be installed by then or the mine would have to close.

Orders like that one result from the well-publicized dangers of the tiny asbestos fibers, both to those who work with them and to others who inhale them from the atmosphere. The irritating, indestructible fibers have been shown to cause lung cancers and other diseases. Apparently no records have been kept on the incidence of lung cancer among the miners here, but certainly the mine hasn't been spared health problems: Between 1951 and 1973, the Vermont Health Department says, at least 16 of the local miners were found to have contracted asbestosis, a progressive, nonmalignant but sometimes fatal lung disease that stiffens the lungs and makes breathing difficult.

The miners generally play down the dangers of breathing asbestos dust. "I've known fellows who worked at the mine 50 years and never had any trouble," says Earl Jones, 51, a maintenance man who has spent 29 years at the mine—so far, he says, with no ill effects. "I worry more about atomic radiation from power plants than all the dust that will ever come from this mine," says Maurice Eldred Jr., 48, a truck driver.

Reproduced from best available copy.

Asbestos product manufacturing, the U.S., however, is much more widespread, is often located in urban areas and generally creates waste dumps that are dry and susceptible to wind erosion.

Chrysotile asbestos waste is rich in magnesia as the data in Table 7 show. In texture, asbestos wastes tend to be porous to water. The pH of asbestos tailings is highly alkaline (pH ~ 9) (Collings et al., 1974). Both the texture and the pH could be improved for vegetation by mixing asbestos tailings with acidic coal mine spoils or acidic waste from metallic sulfide ore mining.

Table 7. CHEMICAL ANALYSES OF CHRYSOTILE ASBESTOS TAILINGS
[Collings et al., 1974]

Sample	Weight %									
	MgO	SiO_2	Fe_2O_3	H_2O	Al_2O_3	CaO	Na_2O	K_2O	LOI	Total
Tailings No.1	41.37	37.50	6.76	0.54	0.30	0.40	0.05	0.05	13.29	100.26
Tailings No.2	39.85	36.65	9.32	0.54	0.83	0.56	0.06	0.08	12.59	100.49
Tailings No.3	40.07	37.84	7.65	0.38	0.31	0.20	0.07	0.05	13.41	99.98

LOI = loss on ignition.

4. .4 Copper Tailings

Copper mining takes place in the arid and lightly populated Western U.S. but some of the tailings may be deposited in the vicinity of population centers (e.g., Butte, Montana).

The tailings are fine sized particles transported from the ore flotation mill to slurry ponds by water. As long as the pond is wet, wind erosion is no problem. Once the pond becomes inactive or dries up, wind erosion may be severe. Low rainfall and blowing dust or sand compound the difficulty of establishing a vegetative cover.

Copper tailings, like most tailings, consist largely of sand, silt, and clay sized fractions so that virtually all of the tailings are soil-sized particles. Some physical and chemical properties of copper tailings are presented in Tables 8 and 9. The cation analysis of Table 8 is based on ammonium acetate extract at pH 7.0. The analyses of Table 8 reflects considerable variation in properties, particularly the soluble salts content as determined by conductivity. Here, as is true for most tailings, each tailing pile must be considered individually. Few general statements can be made that will apply to all copper tailings.

Part of the problem is age. The Hurley, New Mexico tailings exhibit an unusually low pH (2.1) (Table 8). The freshly deposited tailings at this site, however, have a basic pH like most of the others. Aging and weathering processes produce a sharp decline in pH as illustrated in Figure 8. The cause of this acidic drift is most likely the biochemical oxidation of pyrite (FeS_2) with the subsequent formation of sulfuric acid. Sulfur compounds in any tailings or spoils generally result in acidic soil.

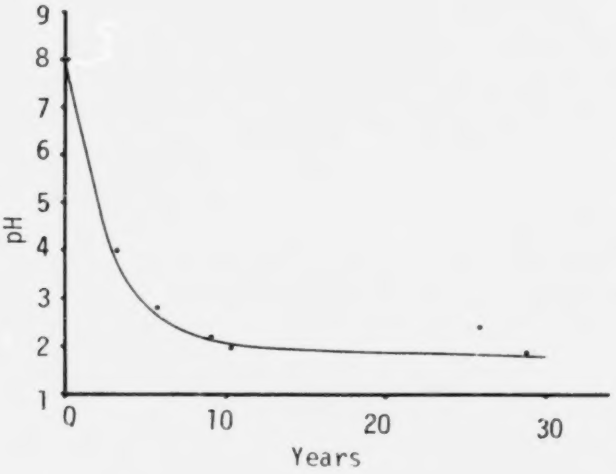


Figure 8. Aging effects upon the pH of copper tailings (Hurley, N.M.) [Nielson and Peterson, 1972].

The concentration of soluble salts also varies with time. Rainwater dissolves the salts and produces a decrease in soluble salt concentration; if the tailings pile is adequately permeable, natural weathering processes will eliminate the objectionable concentrations of salts existing in most copper tailings (Table 8). This leaching action will most likely be slow.

Table 8. ANALYSIS OF COPPER TAILINGS FROM VARIOUS SOURCES [Nielson and Peterson, 1972].

Source	*pH*	*EC_e*	*P*	*K*	*Cu*	*Fe*	*Mn*	*Zn*
			ppm	ppm	ppm	ppm	ppm	ppm
Anaconda, Montana	8.4	2.1	2	29	150	4	36	31
Butte, Montana	5.7	3.2	3	29	600	1	45	88
Hurley, N. Mex.	2.1	10.2	3	23	110	41	2	2
Magna, Utah	7.9	18.0	11	7	104	0	2	2
McGill, Nev	7.6	3.4	--	--	94	--	17	4
Miami, Arizona	7.8	3.6	4	94	90	0	8	1
San Muel, Arizona	7.9	3.8	1	187	43	1	9	2

Note pH--------saturation paste
EC_e------ mmhos/cm, saturation extract
P---------- bicarbonate soluble
Cations--NH_4OAc extract pH 7.0

Table 9. CHEMICAL ANALYSIS, MICROSCOPIC EXAMINATION AND SCREEN ANALYSIS OF SAND AND SLIME PORTIONS OF COPPER TAILINGS FROM MAGNA, UTAH [Nielson and Peterson, 1972].

	Chemical analysis, percent											
Sample	SiO_2	Al_2O_3	Na_2O	K_2O	MgO	CaO	Cu	Fe	Ni	S	CO_2	TiO_2
Sand	74.4	9.6	1.0	5.3	3.0	1.5	.14	2.9	.004	1.6	.15	.35
Slime	65.6	14.0	1.1	5.5	4.9	1.6	.11	2.8	.007	.8	.22	.37

	Mineral composition, percent		
Sample	Sand (coarse and fine-grained)	Mica (mainly Biotite)	Clay (Illite and Montmorillonite)
Sand	65-70	20-25	5-10
Slime	40-45	35-40	15-20

	Screen analysis	
Size	Sand fraction	Slime fraction
+35 mesh	9.6	0.6
-35+65 mesh	36.6	4.0
-65+150 mesh	30.9	5.2
-150+200 mesh	9.3	2.4
-200 mesh + 20 microns	12.0	18.0
-20+10 microns	1.6	18.4
-10+5 microns	--	21.4
-5 microns	--	30.0
	100.0	100.0

The water holding capacity of copper tailings exceeds that of the surrounding desert in Arizona (Ludeke, 1973). However, tailings do not retain water for very long, because of its small clay content and lack of organic matter.

4.2.5 Iron Ore Wastes

Mineral waste associated with iron mining is of three types (Gere, 1970):

1) Tailings -- At present two tons of tailings are produced for every three tons of taconite mined.
2) Overburden
3) Unmerchantable ore -- Stockpiled ore that present market conditions render uneconomical to process.

The major U.S. iron mining region is the Mesabi Range in Minnesota including the Upper Peninsula of Michigan. The intensity and size of the mining operations dominate the area for hundreds of miles. Overburden spoil piles are a familiar part of the countryside.

The ore mined in this area today is no longer the rich red ore deposits of previous years but rather a low grade (iron content less than half that of the top grade ores) dark gray rock called taconite. Settling ponds for taconite tailings are receiving in excess of 50 million tons of fresh waste per year.

Table 10 lists some reported properties of taconite tailings. Texturewise they are composed of nearly 100 percent soil sized particles, although consisting mostly of sand and silt with little clay. Chemically they are rich in iron but low in alkali. Nonetheless the pH of these particular tailings is 8.42 (Nakamura, et al., 1970) and iron ore tailings in general are basic (Shetron and Duffek, 1970).

Iron ore tailings typically are dark grey to red. Water enters the tailings readily but the surface dries rapidly. They require fertilizer to supplement their low levels of plant nutrients.

4.2.6 Lead, Zinc Tailings

Most lead and zinc ores are found in carbonate host rocks such as limestone or dolomitic limestone (Nakamura, et al., 1970). Missouri is the leading U.S. state in lead mining; Tennessee is the leading producer of zinc. The quantity of tailings produced nearly matches the quantity of ore produced so that production information translates easily into the estimates of waste tailings.

Table 10. PROPERTIES OF TACONITE TAILINGS (Wt.%) [Nakamura _et al._, 1970].

a) Chemical Composition

SiO_2	59
Fe	15
Al_2O_3	2.7
MgO	3.7
CaO	2.7
Na_2O	--
K_2O	--
LOI	7.4
Minor Constituents:	
Ni	--
Ti	--
Cu	--
Mn	0.73
Zn	--
S	0.012
P	0.047

b) Texture

Mesh Size	Retained	Cumulative
- 20 + 30	0.10	0.10
- 30 + 40	0.72	0.82
- 40 + 50	2.86	3.68
- 50 + 70	7.48	11.16
- 70 + 100	15.07	26.23
- 100 + 140	13.38	39.61
- 140 + 200	13.89	53.50
- 200 + 325	15.71	100.0

-20 + 30 means that portion of the sample which passes through a No.20 sieve but is retained on a No.30 (see Figure 4).

Table 11. PROPERTIES OF LEAD-ZINC ORE TAILINGS (Wt.%) [Nakamura et al., 1970].

a) Chemical Composition

SiO_2	9.8
Fe	<0.8
Al_2O_3	0.3
MgO	17.8
CaO	29.4
Na_2O	--
K_2O	--
LOI	42
Minor Constituents:	
Ni	--
Ti	--
Cu	--
Mn	0.037
Zn	0.18
S	0.24
P	--

b) Texture

Mesh Size	Retained	Cumulative
- 20 + 30	0.02	0.02
- 30 + 40	0.16	0.18
- 40 + 50	0.83	1.01
- 50 + 70	2.00	3.00
- 70 + 100	2.20	5.15
- 100 + 140	2.10	7.35
- 140 + 200	2.50	9.75
- 200 + 325	4.58	14.30
- 325	86.00	100.00

Because of their high calcium concentration these tailings make valuable agricultural lime and soil conditioners (Table 11). The pH of the tailings is about 7.8. Their fine structure makes them vulnerable to wind erosion.

4.2.7 Uranium Ore Tailings

While uranium tailings are not yet of great magnitude, they are of special interest since they possess radioactivity -- about 70 percent that of the original ore (Beverly, 1970). Some radium, uranium oxides, and radioactive decay products become incorporated into the tailings. Wind erosion from this source is therefore of additional concern because of this added hazard and exposures above the radiation protection guide of 0.5 rem/year can be absorbed downwind of uranium tailings (Havens and Dean, 1969).

Uranium mining is a Western States' activity in the U.S., chiefly Colorado, Utah, New Mexico, Texas, and Wyoming. Chemical analyses of tailings from various locations--Table 12--show wide variation in composition among different locations and in some instances even at the same location. While a relatively recent, post World War 2 mining activity, the low uranium concentrations of ores means that large quantities must be mined.

Table 12. ANALYSIS OF URANIUM TAILINGS FROM VARIOUS SOURCES [Nielson and Peterson, 1972].

Source	*pH*	*EC_e*	*P*	*K*	*Cu*	*Fe*	*Mn*	*Zn*
			ppm	ppm	ppm	ppm	ppm	ppm
Durango, Colorado	7.3	7.4	49	84	12	1	11	12
Mexican Hat, Utah	3.1	9.0	6	18	118	4	86	16
Mexican Hat, Utah	1.9	26	8	68	65	475	525	20
Naturita, Colorado	8.0	2.7	6	35	9	1	2	5
Naturita, Colorado	8.2	4.9	108	82	18	1	9	25
Uravan, Colorado	3.5	63	12	33	5	3	1	4
Uravan, Colorado	3.5	15	17	27	5	2	3	4

Note. pH -------- saturation paste
EC_e ------- mmhos/cm. saturation extract
p ------- bicarbonate soluble
Cations--NH_4OAc extract pH 7.0

Open pit methods now dominate uranium mining so that mineral waste comes from both overburden and tailings. Accumulated tailings alone now exceed 100 million tons (90 Tg) (Beverly, 1974).

4.2.8 Phosphate Mining

Mineral wastes associated with phosphate mining are of three types:

1) Tailings
2) Overburden
3) Slime pits

The first two types of mineral waste are characteristic of all surface mining operations. Overburden in Tennessee is relatively shallow (several feet) (Morgan and Parks, 1967) so its volume is small and its properties very similar to the surrounding unmined land. In Florida the overburden is often better farmland than the adjoining unmined land (Moorman, 1975). The tailings and the slime pits both result from washer and beneficiating processes which separate the sand from the phosphate ore. The sandy tailings settle out relatively rapidly but the phosphatic clay particles, on the order of 2 μm in size, form a fine colloidal suspension which is exceedingly difficult to separate. This slime, consisting of 2-6 percent solids (Florida Phosphate Slimes Problem, 1975), is pumped to settling ponds in the mined out areas and its vicinity. In Florida, producing 75 percent of the total U.S. phosphate rock production (25 percent of the world production), the growth of these slime ponds now poses a problem. They represent lost water, lost phosphate mineral and lost land. They are not a dust problem, however.

4.3 INDUSTRIAL SOURCES OF MINERAL WASTE HEAPS IN THE U.S.

Mineral wastes accompany many industrial processes and their disposal creates a potential air pollution problem (like the wastes associated with mining and ore beneficiation) when the practice is to dump these industrial wastes in large heaps in the open air. As with mining, a major source of industrial mineral waste originates with coal. Coal produces mineral waste during mining, during beneficiation and during or after use--when combusted. The fly and bottom ash and boiler slag of coal burning power plants constitues still another source of mineral waste attributable to coal. Fly ash in particular is susceptible to air erosion.

Table 13. PROPERTIES OF PULVERIZED FUEL ASH (PFA) [Townsend and Hodgson, 1973].

a) Typical Composition

	%	RANGE
SiO_2	48	40 to 60
Al_2O_3	26	20 to 40
Fe_2O_3	10	6 to 16
CaO	4	2 to 10
MgO	2	1 to 4
SO_3	1	0.5 to 2
$Na_2O + K_2O$	4.5	2 to 6

b) Available Macronutrient Content of PFA and a Fertile Soil (Percent)

Nutrient	PFA		Soil Available
	Total	Available	
N	0.035	—	0.180*
P_2O_5	0.114	0.033 (0.013 to 0.054)	0.022
K_2O	2.68	0.042 (0.008 to 0.115)	0.027
Ca	4.69	0.990 (0.28 to 1.87)	0.080
Mg	0.71	0.150 (0.008 to 0.516)	0.024
Fe	6.09	0.057 (0.001 to 0.229)	0.013
S	0.48	0.390 (0.07 to 0.55)	0.060

* Total; not available.

c) Available Micronutrient Content of PFA and a Fertile Soil (ppm)

Nutrient	PFA		Soil Available
	Total	Available	
Mn	848	99 (12 to 347)	4.8
B	236	43 (3 to 150)	2.5
Zn	283	2.1 (0 to 4.0)	2.5
Cu	248	25 (10 to 50)	2.5
Mo	42	5.4 (0.7 to 12.8)	0.2

. Table 13 (cont'd)

d) Content of Available Trace Elements in PFA and Soil (ppm)

Element	PFA	Soil	Element	PFA	Soil
Ag	1	1	Pb	10	10
Al	144	58	Se	—*	2
Co	8.5	1.6	Sn	10	10
Cr	22	1.7	Ti	15	10
Ni	60	2.7	V	6	1.3

* Not detected

e) Particle-size Analysis of PFA (% by wt)

Sample	Coarse sand 2.0–0.2 mm	Fine sand 0.2–0.02 mm	Silt 0.02–0.002 mm	Clay <0.002 mm
A	3	51	45	1
B	1	31	64	4
C	1	40	58	1
D	<1	26	70	4

4.3.1 Pulverized Fuel Ash (PFA)

PFA is the ash remaining from the combustion of pulverized coal, a typical power plant fuel. Its properties are summarized in Table 13. A comparison of the nutrients and trace elements in PFA with those in fertile mineral soils is also included in Table 13. Total lack of nitrogen in PFA is one outstanding difference. Potential phytotoxicities may exist in PFA because of the excess boron.

PFA is highly alkaline (pH ~ 8-12). It also possesses pozzolanic properties (forms a cement with lime and water). Soluble salts produce a conductivity that is typically in the 8-13 mmho/cm range (Townsend and Hodgson, 1973).

4.3.2 Spent Shale

Spent shale is the left over waste following oil extraction from oil shale. This source of mineral waste will become significant if oil shale proves to be an economical alternative source of fuel in the U.S.

Oil shale resources cover more than 11 million acres (45 Gm^2) of Colorado, Utah and Wyoming (Schmehl and McCaskin, 1973) and since 80 to 90 percent by weight of the oil shale rock ends up as spent shale, reclamation success will play a major role in determining the economic viability of the process--hence, the interest in what is still only a potential mineral waste problem.

Properties of the spent shale resulting from two candidate processes appear in Table 14. The pH is highly basic and the concentration of soluble salts is high. Particle size and moisture holding properties are adequate. The TOSCO process shale consists of finer grained particles than the gas combustion process but both lack adequate phosphorus and nitrogen.

Other candidate processes for recovering oil from shale have been proposed including an underground retort method (Cook, 1974). All methods involve heating the shale for oil recovery and, although some spent shale properties depend on the process, all produce a highly alkaline, highly saline residue material similar to that described in Table 14.

4.4 SUMMARY

Mineral waste heaps constitute a mixed lot. Their properties depend on their origin but also on many other variables. Under past production methods, little attention has been given to waste heap properties and they have accumulated and been piled up more or less at random. With some preplanning and control, waste piles could be made more uniform and predictable which would greatly simplify revegetation procedures.

At present only the most general statements can be made about mineral waste heaps. The detailed description of each existing pile is likley to differ significantly and each pile requires an individual analysis.

Table 14. PROPERTIES OF SIX SPENT SHALE SAMPLES [Schmehl and McCashin, 1973].

a) Fertility and Salinity

Spent Shale Designation	Lab. No.	Retort Process	Conductivity[a] mmhos cm 25 C	pH Saturation Paste	pH 1 : 5 Shale : Water	$CaCO_3$ Equiv. %	Available Nutrients P ppm	K ppm	Zn ppm	Fe ppm
A	3766	Tosco II	16.0	9.7	9.9	40.0	8.5	27		
B	7972	Tosco II	11.3	9.1	9.4	11.0	3.7	40	>10.0	>40
C	4216	Tosco II	26.0	8.9	9.3	31.2	6.7	135	8.4	>40
D	240	Gas Combustion	9.0	8.6	9.2	31.4	5.6	360	4.7	>40
E	241	Gas Combustion	22.0	8.7	9.0	31.2	3.6	>400	5.8	>40
F	243	Gas Combustion	12.0	8.7	9.0	30.8	3.6	>400	2.9	>40

[a] Conductivity of the solution removed from spent shale saturated with distilled water (Richards, 1954).

b) Water Soluble Ions in a Saturation Extract.

Ion	Spent shale designation A	B	C	D	E	F
	Equivalents per million					
Ca^{++}	26.4	21.2	18.5	31.5	20.0	19.5
Mg^{++}	1.6	18.4	78.5	12.0	34.5	77.5
Na^{+}	124.0	113.1	195.8	37.0	156.6	30.5
K^{+}	1.4	0.7	2.6	7.0	16.6	9.0
$CO_3^{=}$	5.9	0.2	1.2	0.0	0.8	0.4
HCO_3^{-}	1.9	3.0	1.6	0.6	1.8	0.8
Cl^{-}	3.0	1.0	4.5	0.8	2.5	2.5
$SO_4^{=}$	137.5	139.3	266.3	99.3	191.8	123.5
SAR[a]	33.1	25.5	28.4	8.0	30.2	4.5

[a] SAR (Sodium Adsorption Ratio) $\dfrac{Na}{\left(\dfrac{Ca + Mg}{2}\right)^{\frac{1}{2}}}$; Na, Ca, and Mg expressed in equivalents per million in saturation extract (Richards, 1954).

Table 14 (cont'd)

c) Particle Size, Field Moisture Capacity and Cation Exchange Capacity.

Sample Designation	Particle Size—% of Total			Field Moisture Capacity*	Cation Exchange Capacity, 2-mm Fraction
	>8 mm	8-2 mm	< 2 mm	%	meq/100 g
A	0	20	80	18.5	7.6
B	0	11	89	22.2	5.6
C	0	11	89	20.4	6.0
D	29	23	48	22.1	7.8
E	43	33	24	20.5	8.0
F	31	25	43	16.8	8.6

* Total material for samples A, B, C; 2-mm fraction for samples D, E, and F.

4.5 RECOMMENDATIONS

If miners can be convinced that they can make money on reclaimed land, the problem is solved. At present, laws compel mines and other sources of mineral waste to carry out a certain minimum of land restoration. They comply-grudgingly perhaps--because they must. What is needed is wholehearted, enthusiastic efforts -- not just the legal minimum. The surefire way to achieve such support is to make it profitable. The motto and guiding principle must be that land can be made more valuable after surface mining than before, that the mining operation is a beneficiating, soil rejuvenating operation capable of extending and broadening the land use options of a given site.

5.0 CONTROL METHODS FOR FUGITIVE DUST EMISSIONS FROM MINERAL ORE WASTE HEAPS

The piles of mineral wastes listed in Section 4 are objectionable for a number of reasons; they are unsightly, they sometimes release toxic liquids into local water, they often prove unstable with catastrophic consequences--i.e., the landslides in Wales. The property of most interest in this report is none of these, however; it is rather their potential as sources of fugitive air emissions. Barren, unprotected piles of mineral wastes create ideal feedstock for wind erosion and fugitive dust clouds. This section reviews methods of minimizing the fugitive dust emissions from mineral waste piles. Before discussing these methods, however, a brief review of wind erosion and mass transport via the air will be presented to better define the variables that must be controlled.

5.1 WIND EROSION

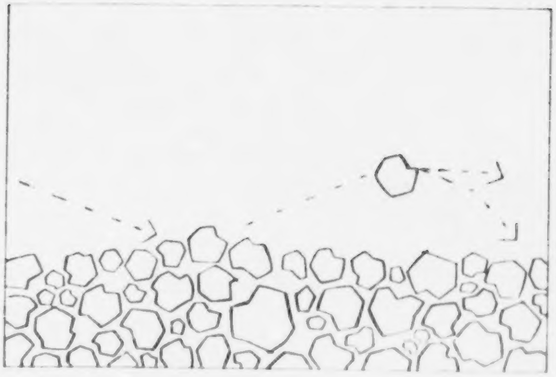
Wind erosion moves soil by three modes of transport (Figure 9):

1) Saltation
2) Surface Creep
3) Suspension

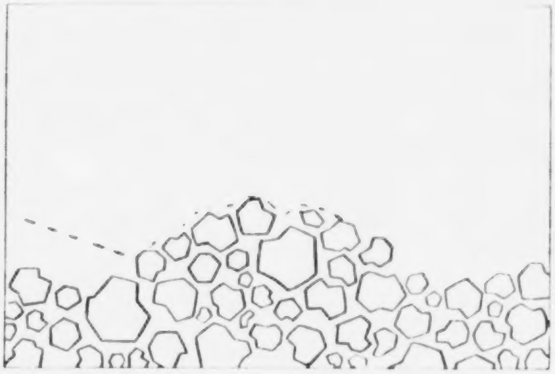
Saltation is the skipping or leapfrogging of windblown particles over a surface. The particles become airborne by gusts or by impact from other particles but are too heavy to remain airborne for long. A typical trajectory of a particle moving in saltation is sketched in Figure 10. The maximum height, h, of the trajectory seldom exceeds 1 meter; most saltation occurs within a few cm of the ground (The Coherex Manual...,1970).

Surface creep is particle motion along a surface without becoming airborne. These particles are impacted and blown on as in saltation but are too heavy to become airborne at all.

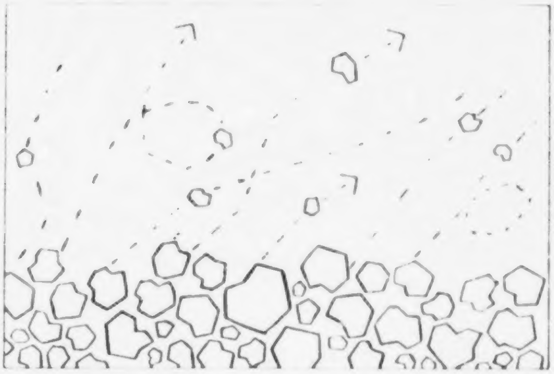
Suspension is the process whereby particles become airborne and do not settle rapidly but rather are blown long distances. This mode of transportation applies to small particles only as indicated in Figure 11, and is the most significant mode from an air pollution point of view.



a – Saltation



b – Surface Creep



c – Suspension

Figure 9. Modes of soil movement. [The Coherex Manual, 1970).

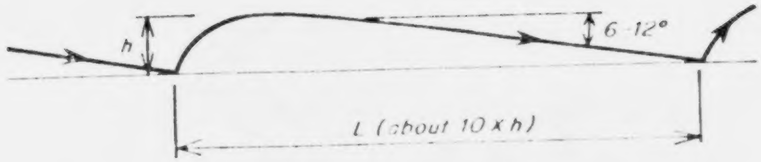

h
6-12°
L (about 10 x h)

Figure 10. Particle trajectory during saltation [Hudson, 1971].

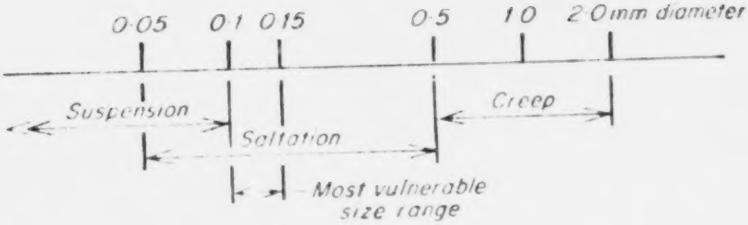

0·05
0·1
0·15
0·5
1·0
2·0 mm diameter
Suspension
Saltation
Creep
Most vulnerable size range

Figure 11. Dominant mode of windblown soil transport as a function of particle size [Hudson, 1971].

Although much more soil mass is transported by the saltation process, the long range impact on ambient suspended particulate concentration by soil moving in saltation is negligible except for the indirect interaction whereby saltation increases the concentration of airborne suspended particles by impact. This added component contributes to the measured densities of suspended particulates.

Conventional wind erosion equations attempt to account for all mass transport from a surface. Saltation and creep are far more important by this measure.

Wind erosion depends upon eleven primary variables (Woodruff and Siddoway, 1965).

1) Soil Erodibility Index -- The soil erodibility index is the rate of mass loss, experienced by an unsheltered, flat, smooth, noncrusted surface of a soil when exposed to the climatic conditions that were characteristic of Garden City, Kansas during 1954-1956. It measures texture or average effective particle size in the soil.

2) Knoll Erodibility -- Knoll erodibility is a correction factor to account for the enhanced erosion on the windward side of slopes in the terrain.

3) Surface Crust Stability -- Surface crust stability is a correction factor to account for the mechanical stability imparted to the surface by the presence of a protective skin.

4) Soil Ridge Roughness -- Soil ridge roughness is a measure of the effect of undulations or periodic departures from flatness in the eroding surface.

5) Wind Velocity.

6) Soil Surface Moisture.

7) Field Dimension along the Direction of the Wind.

8) Sheltered Distance -- Sheltered distance is the distance in the wind direction that is sheltered by an adjoining barrier.

9) Quantity of Vegetative Cover -- The quantity of vegetative cover is a measure of the vegetative mass per unit area.

10) Kind of Vegetative Cover -- The kind of vegetative cover is a weighting factor according to the total cross-sectional area of the vegetative species.

11) Orientation of Vegetative Cover -- The orientation of vegetative cover includes the effects of row direction and spacing upon the wind interaction and any directional dependence of the [illegible]tion presented to the prevailing wind.

Reduction of these eleven variables to five, more or less, independent variables is discussed in Appendix A.

5.2 CONTROL METHODS

Four general categories of control methods for fugitive emissions from mineral waste heaps exist: 1) physical control, 2) chemical binding layers, 3) vegetative cover, and 4) shelterbelts. This section reviews the four major methods and the principles upon which they depend.

The most difficult method to apply is that of vegetative cover which is also generally the preferred method. Ofttimes the vegetative cover method follows a physical or chemical method used to achieve temporary control. The net result is a combination control method which achieves results superior to any one method alone.

5.2.1 Physical Control Methods

Physical control methods involve the placing of a separate cover or barrier over the waste pile in order to reduce the wind speed relative to the fine particulates of the pile, consolidate the surface by binding particles, impede moisture loss from the surface and generally protect and isolate the underlying waste from the environment. Physical methods effect control by putting a lid over the waste, or isolating it within an enclosure. The freedom and ease of interaction of the surface with the environment is reduced.

A common physical control is to cover the waste pile with a layer of soil, rock or gravel from the surrounding area, more or less burying it. This technique is primarily one of reducing the soil erodibility index (variable number 1 of the 11 primary variables cited in Section 5.1). If the covering soil also facilitates the re-emergence of vegetative characteristic of the area, so much the better.

Paving a dirt road with concrete or asphalt is a highly successful physical control method for reducing fugitive emissions from roads. It is also so highly expensive that no serious consideration to letting road paving contracts for mineral waste piles has been made, although variations of the technique have been investigated. Typically, such coverings will be water based elastomeric films, resins, rubber, asphalt, starch, latex or oil emulsions, lignin sulfonate, wax, tar, or pitch. (Mittelstadt and Davis, 1973). Any of a variety of materials can be sprayed or poured over the pile to subsequently produce a protective cover. This technique is analogous to painting the pile whereby the pile surface is protected from the environment by the application of a thin foreign layer, physically adhering to the surface. Such preparations are classified as chemical coatings or binding layers and are discussed in Section 5.3.

Water spraying is the time honored physical control method; it works well for some mineral wastes. Simply by continually wetting down a pile, the magnitude of the fugitive dust emissions drops significantly. As reflected in equations 1 and 2 (Appendix A), the wind erosion rate varies as the inverse square of soil surface moisture. Wetting is a straight-forward method of reducing wind erosion by maintaining high surface moisture. Sprinkling systems for periodically spraying a pile are now in use (Automated Stockpile...,1971). Typically, a multi nozzle array of small sprayers produces better coverage than a single high volume nozzle. Directional capability in response to prevailing wind direction and magnitude improves the accuracy and effectiveness of the spraying. A complete system, therefore, should include wind measuring equipment and appropriate controls to adjust the nozzles to optimize coverage.

A chief drawback of the watering method is that it is only a temporary control. The sprinkling system must be in place ready to spray more or less continuously, depending on climatic conditions. Such a system, while relatively inexpensive to operate and even to install, requires vigilance in monitoring in order to maintain effectiveness. Climatic variables such as lack of readily available water and/or freezing plumbing, influence the operating costs and effectiveness of the system.

Improved fugitive dust control of a pile by spraying can be achieved by adding a surface active agent to the water in order to reduce the surface tension of the water and, thereby, increase its dust wetting properties (Dust Suppression..., 1972). Typically, dilution of a 1 part wetting agent to 1,000 parts water lowers the surface tension from 0.075 N/m (75 dynes/cm) to about 0.025 N/m (25 dynes/cm) (Chem-Jet Dust...).

Enhanced wetting means that less water solution is required to create similar agglomerating and stabilizing characteristics into the surface layer of the pile--water to the extent of 1/2-1 percent of the pile weight is necessary with a wetting agent versus 5-8 percent moisture (by weight) when using untreated water (Dust Suppression..., 1972; Chem-Jet Dust...). Even when using a wetting agent, however, the need still exists for periodic spraying in order to maintain a moist protective surface layer.

Wetting agents are generally organic chemicals composed of a long chain hydrocarbon and a hydrophylic group such as sulfate, sulfonate, hydroxide, ethylene oxide, etc. When added to water, these molecules migrate to the surface with the hydrophylic group in the water and the hydrophobic hydrocarbon group in the air. This configuration reduces surface bonding forces and results in lower surface tension than for untreated water. The lower surface tension makes it possible for many particulates to penetrate into the bulk of the water rather than be confined to the surface.

Other physical covers include bark, straw, wood chips, crushed or granulated smelter slag. All of these, except slag most likely, would be used as mulches in conjunction with the establishment of a permanent vegetative cover. As such, their effectiveness needs to be but temporary.

5.2.2 Chemical Binding Materials

Chemical binding materials are those surface coatings consisting of a specially prepared material which is poured or sprayed over the waste pile and, which, upon drying or curing, forms an adherent, conformal protective coating. The term chemical implies that the layer consists of a manufactured preparation with composition and properties tailored specifically for pile protection. The binding action refers to the physical interaction between the chemical layer and the particulates in the surface of the protected pile which are glued together by the chemical layer to form an erosion resistant crust. The action of a chemical binding layer is comparable to covering the pile with a viscous liquid sealant which solidifies into a hard protective shell.

In spite of the title of the classification, no chemical reaction generally takes place between the pile and the coating even though adhesive bonding occurs. Over a wide spectrum of dry mineral wastes (water content can affect adhesion) the adherence and effectiveness of the chemical coating are independent of the chemical composition of the pile. The pile, in turn, is unchanged in chemical composition once the binding layer is physically or chemically removed.

Consequently, the only difference between the chemical binders discussed in this section and the physical methods described in Section 5.2.1 is that the chemical surface layers are specially formulated chemical solutions which are applied as liquids or viscous solids. The mechanisms for reducing or minimizing fugitive emissions are similar--chemical surface layers, like the physical covers, isolate the pile from the environment. Since chemical layers create a thin skin of protection rather than a heavy covering (like most physical layers), they offtimes are not as rugged or long lasting (Frost and Piper, 1968). For certain waste piles, however--particularly those requiring only temporary protection--they may offer the most cost-effective solution. These materials are particularly useful for temporary protection while a vegetative stand is being established. Consequently, chemical binding layers are of special importance in this report for their potential use in combination chemical-vegetative control methods.

5.2.2.1 Types of Chemical Binding Layers -- Of the many chemical compositions tested for mineral waste pile protection, the Bureau of Mines at Salt Lake City rank the coatings as listed in Table 15.

These chemicals are typically sprayed over the pile to be protected and provide anywhere from short-term to multiple-year protection against wind erosion. Work at Salt Lake has been aimed mainly at use of a chemical binding surface layer in conjunction with vegetation.

In a typical application seed, wood fiber, chemical adhesive, fertilizer and water are slurried together in a mixing tank (~2000 gal) mounted on truck. The solution can be pumped through a nozzle at high pressure and sprayed over the pile to be stabilized. Such an operation is a two-man job and can plant/coat 2 to 4 x 10^4 m^2/day (5 to 10 acres/day) (Carter *et al.*, 1974).

Tabel 15. CHEMICAL BINDING SURFACE TREATMENTS IN DESCENDING ORDER OF RANK BY THE USBM, SALT LAKE CITY [Dean, et al., 1974].

Name	Description	Dose	Cost	Remarks*	Supplier
Coherex	Resinous Adhesive	0.224 ℓ/m^2 (240 gal/acre)	1.6¢/m^2 ($65/acre) 16¢/m^2 ($650/acre)	Good wind resistance Good water jet resistance	**Witco Chemical Co.**
Lignosulfonates	Calcium, Sodium, Ammonium } Lignosulfonates	0.269 kg/m^2 (2400 lb/acre)	3.2¢/m^2-4¢/m^2 ($130-$170/acre)		
SP-400 Soil Gard	Elastomeric Polymers	0.051 ℓ/m^2 (55 gal/acre)	3.2¢/m^2 ($130/acre)	Exceptionally effective on sandy tailings; satisfactory on both acidic and alkaline tailings	**Alco Chemical Co.**
DCA-70		0.084 ℓ/m^2 (90 gal/acre) 0.047 ℓ/m^2 (50 gal/acre)			**Union Carbide**
Cement & milk of Lime			4.7¢/m^2 ($190/acre)		
Paracol TC 1842	Resin Emulsion		6.2¢/m^2 ($250/acre)		
Pamak WTP	Wax, tar & pitch product		6.2¢/m^2 ($250/acre)		
Petroset SB-1	Elastomeric Polymers		6.2¢/m^2 ($250/acre)		**Phillips Petroleum**
Potassium silicate, having an SiO_2 to K_2O ratio of 2.5			11.1-23.5¢/m^2 ($450-$920/acre)		
PB-4601	Polymeric Stabilizing Plant		12.4¢/m^2 ($500/acre)		
Reosol Cationic Neoprene	Elastomeric Polymer Emulsion		12.4¢/m^2 ($500/acre)		
Dresinol, TC 1843	Ammonium Casein		12.4¢/m^2 ($500/acre)		
Sodium Silicates having ratios of 2.4 to 2.9 SiO_2 to 1 Na_2O			4.9¢/m^2 ($200/acre)	Calcium chloride can be used in place of some of the sodium silicate	

*Test conditions consisted of:

a) water jet at various pressures to simulate water erosion.

b) wind tunnel at 0 to 161 km/hr (100 mph) and various orientations to simulate wind erosion.

One striking success is the stabilization of copper tailings from a mine in McGill, Nevada (Dean, et al., 1969). The surface is physically heterogeneous, varying from sand to slime; high salt, low salt, etc., and many combinations thereof. At the McGill site, five days after planting, Coherex[R] solution, diluted with 4 parts volume by water was sprayed at a dose of 0.815 ℓ/m^2 (0.18 gal/square yd). The treatment successfully protected the emerging vegetation from wind blown sand damage and exhibited stabilizing properties until the vegetation was established. Total costs, including those of seeding, fertilizing and all labor, amounted to 3.35¢/m^2 ($134.50/acre) (Dean, et al., 1969). Chemical binders have also been used where conditions prevented any use of vegetation cover. At the uranium mine tailings pile near Yuba City, Arizona (Havens and Dean, 1969), DCA-70 was used on the dike areas of the tailings ponds and calcium lingonosulphonate, on the beach areas. Both water-soluble chemicals were applied with an automated sprinkling system. These coatings failed only at points where physical damage was initiated by human activity or animals or at certain points where complete coverage was not achieved because of discontinuities in the terrain.

Total cost was 8.28¢/m^2 ($335/acre) (Dean and Havens, 1971).

5.2.3 Vegetative Cover

A vegetative cover for mineral tailings is the preferred control method. It is aesthetically pleasing and represents, at least on the surface, restoration of the landscape; when self-sufficient, it constitutes a truly permanent solution to wind erosion; in addition, the potential for harvesting product offers an economic bonus not available with other methods.

Establishing vegetation is not generally easy. What is required at a minimum is adequate:

1) light
2) temperature
3) air
4) water
5) nutrients

[R] Registered tradename of Witco Chemical Corp.

6) freedom from phytotoxicants

7) protection for physical damage by abrasion

Under most climates the first three requirements present no problem. Water may not always be adequate and sometimes successful vegetative cover requires irrigation.

On the last three counts waste piles are often deficient. Until shown otherwise, waste piles should be considered (Dean, et al., 1971):

1) deficient in plant nutrients,
2) to be composed of excessive salts and heavy metal phytotoxicants,
3) subject to damage from windblown sand,
4) lacking in normal microbial populations,
5) vulnerable to animal grazing damage.

Each of these potential shortcomings or vulnerabilities must be remedied or guarded against for successful vegetative covering.

Composition is the most important property of the waste pile in assessing suitability and strategy for vegetation. By chemical analysis of the wastes, the nutrient level and the phytotoxicant level become known. Nutrients required for plant growth include nitrogen, calcium, potassium, phosphorus and trace quantities of various metals. Nitrogen is invariably deficient and must be added. With the proper choice of nitrogen fixing vegetative species and organic matter, the nitrogen balance can be restored without continued supplement.

The concentration of alkalies and heavy metal salts may be deficient or may be too great. If the former, they constitute a deficiency to be made up; if the latter, a phytotoxicant to be compensated or reduced. For example, copper in concentrations of 1000 ppm is not generally phytotoxic while nickel above 100 ppm and zinc above 10 ppm are.

A key measure of spoil composition and suitability for vegetation is its pH. pH is a relative measure of soil acidity/alkalinity and correlates well with the availability of plant nutrients (see Figure 12). It is this dependence rather than a direct interaction between the hydrogen ion and the plant that makes crop performance so highly pH dependent.

Figure 12 shows the availability of various plant nutrients as a function of pH, the width of any given bar being proportional to the

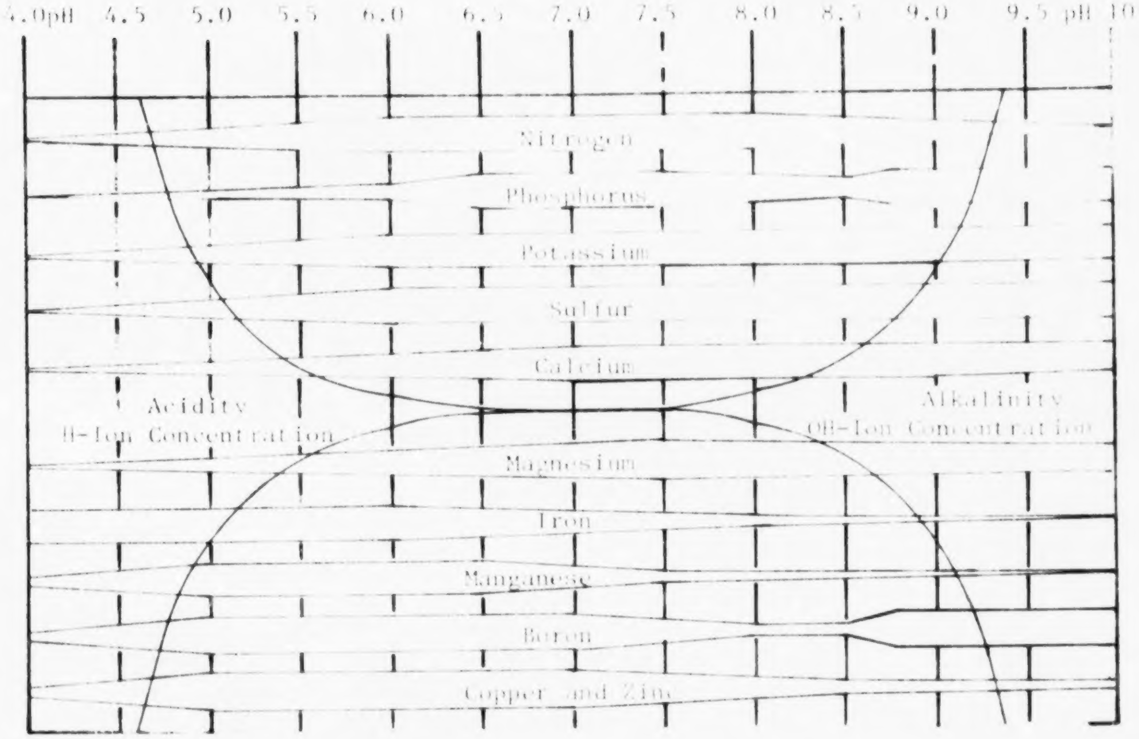


Figure 12. The availability of plant nutrients as influenced by acidity [Carter et al., 1974].

availability of the labelled chemical. The solid lines plot the hydrogen (or hydroxide) ion concentration as a function of pH.

The most favorable value of pH is about 6.5 where all the nutrients shown exist in ample supply. Generally, however, the pH range from 4 to 8 is considered feasible for vegetation, although selection of species becomes important at the acid extreme.

For vegetating highly acidic spoils, lime pretreatment raises pH and improves growth as reflected by the data in Figure 13. The growth of these pine trees varies with spoil pH which in turn depends upon lime dose as given in the treatment key. The trace metal content of the tree tissue also depends upon lime strength as listed in Table 16 for the same experimental trees.

An additional complication of assessing the chemical composition of tailings is their time dependence. In spoils rich with pyrite (FeS_2), for example, the soil pH decreases with time as the pyrite slowly reacts, forming sulfuric acid, due to bacterial action of Thiobacillus thiooxidens which is an aerobic bacteria. Under anerobic conditions D. desulfuricans can reduce sulfates to sulfides. Failure to anticipate this chemistry can lead to crop failures. On the other hand, rainwater and natural washing can leach many salts from a spoil pile that would otherwise render it unsuitable for vegetation. Regardless of what action occurs the point to be emphasized is that a major difference between mineral tailings or overburden from strip mining on the one hand and agricultural surface soil on the other hand is the state of equilibration with the atmosphere and surface environment. Agricultural soil (or any surface soil) has already weathered the natural processes to achieve a relatively stable chemical composition and physical state; previously buried spoils or overburden have not. Consequently, in general, the initial analysis of freshly formed waste will not necessarily be the same as the composition of that same waste pile after long-term exposure to the surface weathering processes. Immediate spoil analysis, however, is urgent in order to plan those steps necessary to hasten the desirable changes and halt the undesirable changes.

Other properties of a waste pile that are important in planning vegetative cover include spoil texture, homogeneity and grade. Almost universally, vegetation grows better in soils or spoils that are uniform, level, and composed of fine particles of assorted sizes (the various

Treatment	pH
Check (No lime added)	3.5
2 tons lime/acre (0.45 kg/m^2)	3.9
5 tons lime/acre (1.12 kg/m^2)	6.6
10 tons lime/acre (2.24 kg/m^2)	7.6

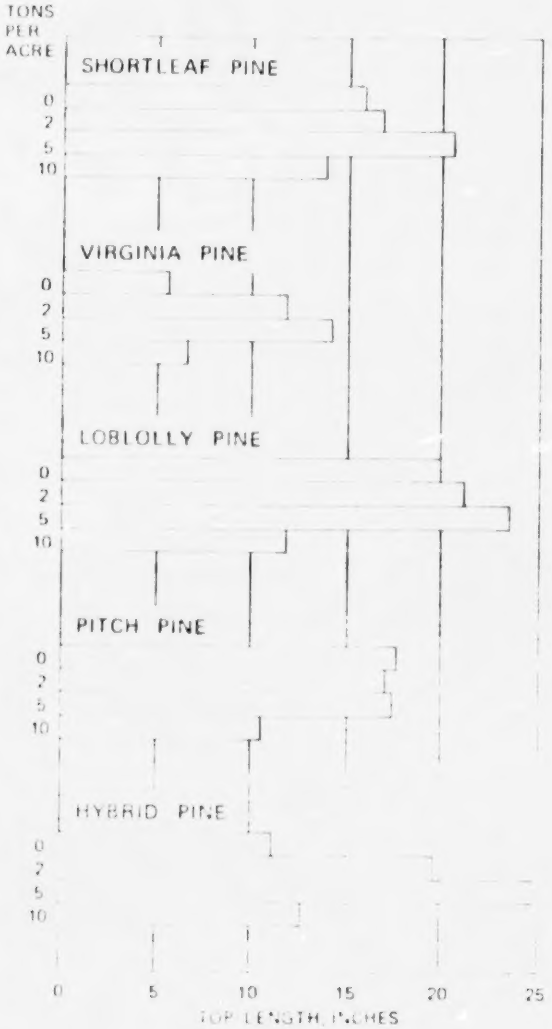


Figure 13. Dependence of pine growth upon lime treatment [Plass, 1969].

Table 16. AVERAGE NUTRIENT CONTENT OF TISSUE FROM THE PINE TREES DESCRIBED IN FIGURE 13. [Plass, 1969].

Lime added, tons/acre (kg/m^2)	0	2 (0.45)	5 (1.12)	10 (2.24)	Differences between treatments were:
pH	3.5	3.9	6.6	7.6	
NUTRIENT	Pct.	Pct.	Pct.	Pct.	
Nitrogen	1.56	1.22	1.36	1.43	Not determined[1]
Phosphorus	0.15	0.15	0.12	0.09	Significant[2]
Potassium	0.53	0.60	0.59	0.73	Not significant
Calcium	1.28	0.90	2.10	2.78	Highly significant[3]
Magnesium	0.33	0.26	0.18	0.13	Highly significant
	ppm	ppm	ppm	ppm	
Iron	1,998	1,150	818	871	Highly significant
Manganese	750	789	421	218	Highly significant
Aluminum	3,129	2,996	2,868	2,728	Not significant
Copper	43	29	20	24	Highly significant
Zinc	76	62	36	37	Highly significant
Boron	38	44	38	21	Highly significant
Molybdenum	5.06	4.22	2.82	3.22	Significant

1. Insufficient data.
2. Statistically significant at the 5 percent level.
3. Statistically significant at the 1 percent level.

loam categories of Figure 3), but with few massive stones--at least on the surface. Too much clay results in poorly drained and aerated spoil; too much sand results in erosion, low moisture and low fertility.

Waste piles do not generally possess ideal properties for the growth of vegetation. They often are highly variable in pH, exhibiting spots of high acidity interspersed throughout the pile or else consist of regions of both basic and acidic soil in the same pile. Selecting the optimum vegetation and preparation strategy for such an inhomogeneous soil is a broad compromise at best.

Spoil banks are not as predictable as they should or easily could be. Soil profiles typically consist of layers of varying compositions and properties, some of which are better suited for vegetative growth than others. The usual practice, however, has been to strip off the layers with a drag line or power shovel and pile the overburden in the nearest convenient spot without regard as to what layer ends up where. This practice greatly complicates the subsequent reclamation efforts and makes it impossible to predict what the key soil parameters will be or to prescribe a vegetative strategy without detailed multi point sampling. Even then, inhomogeneity of the pile may totally invalidate the recommendation that was based on nearby sampling points.

Happily the need for preplanning and foresight in overburden removal is being recognized here in the U.S. (European practice is ahead of the U.S. in this respect) and present and future reclamation projects will not encounter this needless handicap. For old spoil banks, however, inhomogeneity--the random mixture of many soil horizons or layers--remains, guaranteeing poorer results at higher costs.

Without suitable preparation the physical structure of most waste piles is not at the optimum for vegetative cover. With proper planning the waste pile can be distributed, graded and contoured to aid vegetative growth. Location and orientation can sometimes be adjusted at little or no cost so as to have major impact on ease of establishing vegetative cover.

5.2.4 Shelterbelts

A shelterbelt is a growth of trees and/or shrubs maintained for the purpose of sheltering an area from the wind, primarily, but possibly also the sun. Mineral waste heaps that would otherwise by buffeted by prevailing high winds can, thereby, be protected from wind erosion using shelterbelts.

An added benefit is improved aesthetics in that an unattractive waste pile can be hidden from public view.

Adjacent existing vegetation is capable of serving as a shelterbelt during the vulnerable period in which vegetation is being established on the waste pile. The shelterbelt reduces sandblasting of emerging vegetation and can also provide shade to limit surface temperatures. Shelterbelts are an established tool in agronomy and can be used alone or in combination with other methods in controlling wind erosion of mineral waste heaps.

6.0 FUNDAMENTALS OF MINERAL WASTE HEAP STABILIZATION BY VEGETATIVE COVER

The objective of this section is to discuss the general ecological aspects of vegetating the surfaces of mineral waste heaps. As discussed in Section 4 these surfaces are quite varied in nature and may be either anthropogenic or natural in origin. The former category includes land devastated by strip mining, tailing heaps from mineral processing, aggregate piles for construction, and fuel ash from the combustion of pulverized coal. Naturally barren areas include deserts, land where severe erosion is occurring, beach environments, and recently created volcanic areas. Burned areas could be placed in either category depending on the cause.

Adverse effects include loss of valuable topsoil, sedimentation of lakes and streams, upset of wildlife habitats, and destruction of man-made structures (e.g., highways, buildings, and fences). In addition, secondary problems such as airborne dusts interfering with highway safety by reducing visibility, or soiling of homes and clothing may occur.

Vegetative cover can ameliorate and often eliminate these problems by stabilzing barren mineral surfaces. The benefits which stem from the use of plant covers are tremendous when compared to the alternative methods techniques (i.e., chemical surface coating, gravel covers, paving, fibrous mats, and continual wetting (see Section 5)). Many of these alternative techniques require replacement or renewal at finite intervals while vegetation generally represents a permanent solution without the need for long-term maintenance.

The efficiency of vegetation in controlling erosion-related problems is excellent. Aesthetically, there is no comparison between the beauty of plants and other available modes of control. Plants improve soil conditions by increasing ground litter, decreasing erosion, and moderating soil pH. In turn, the area is made more tenable for other plants and will eventually increase the production of woody plants (Holland, 1973). Vegetation will also provide important habitats for wildlife.

On an economic basis, plants generally represent the lowest cost solution over long time periods. Land which is covered by vegetation is generally more valuable than barren land. Recreational benefits are an important aspect of this value. Forest and agricultural (both crops and livestock) commodities may be produced on reclaimed areas (Grandt, 1965). By stopping sedimentation of the reservoirs, by reducing silt loads in runoff water, plants help to provide clean water supplies.

Plants strongly influence the environment, especially their immediate surroundings. They improve the soil by increasing its capacity to retain water and nutrients and adding to its fertility. Their evapotranspiration is important in the water cycle. Plants are significant in their contribution to maintaining balances of oxygen and carbon dioxide in the atmosphere. For example, each acre of a young high-yield forest, besides supplying 4 tons of wood each year, can produce 4 tons of oxygen -- enough for 18 persons for that year (Latimer, 1971).

Vegetative ground covers contribute to the improvement of the whole environment by the reclamation of wastelands. Plant communities are very important ecosystems. They protect the land and preserve its physiographic features. Besides maintenance, they also play a vital role in terrain formation. In cases where topsoil is being blown or washed away, plant covers conserve an irreplaceable resource. Researchers in the field of land reclamation have unequivocably stated that plants are the most desirable agent known for stabilizing mineral surfaces (Berry, 1975; May, 1975; Plummer, 1975). However, landscape planning must be ecologically sound. An assessment of the biological and physical characteristics of an area must be made; the assessment should include facts relating to before and after the mining disturbance. If there are limits to the land use after mining, these should be considered. (Olschowy, 1973).

How do plants control the emission of fugitive dust into the atmosphere? Basically, there are three ways in which plants may suppress this emission or contribute to the removal of airborne dust. First is direct stabilization of the soil surface (i.e., the roots bind the soil and the plant stems and leaves serve as a protective cover), thus preventing the particles from becoming airborne. Second, rows of plants, usually trees planted normal to the prevailing wind direction, may serve as windbreaks (shelterbelts) to reduce wind velocities which would otherwise cause particles to become airborne. Such windbreaks have been used to excellent advantage on the Great Plains of the United States and elsewhere; a wealth of experimental evidence and experience concerning them exists (Bates, 1945; Van Eimern, 1964, Rao, 1970). Last is the removal of suspended dust particles from the air by plants. In this phenomenon, the vegetation serves as a kind of natural filter which collects the dust by impaction. (Langer, 1965; Neuberger, et al., 1967; Podogrow, 1967).

Direct stabilization of the ground medium is the most important way in which vegetative ground covers function and is the only role considered in this report.

6.1 VEGETATIVE FACTORS

6.1.1 Species Selection

Information for the selection of plant species for use in controlling fugitive dust can be derived from the ecology of specific habitats, agronomic experience, and previous field tests. There are two complementary sets of characteristics which will be employed in the selection of plant species for ground surface stabilization. These are the capacities of the plant and the characteristics of the surrounding habitat where the species is to be used. The problem then is matching the plant to the habitat. Preliminary information gathered about the site which includes descriptions of climate (e.g., rainfall, wind speed, and temperature) and soil (e.g., texture, fertility, and pH) will be used in arriving at the species to be planted.

The most important consideration in choosing plants is that the plants serve their intended purpose whether it be control of erosion, aesthetics, or economic production (Vande Linde, 1971). Erosion control and economic production are the pivotal criteria as many species can satisfy the aesthetic requirement. Plants must be selected on the basis of these two criteria.

The best sources of information to utilize in selecting plants are experiences which others have had under similar conditions and data from research designed to study revegetation on similar sites. Since site characteristics are likely to be highly variable, subtle differences which may be significant must be considered. A discussion of current research experience is given in Section 5. In using results obtained by others to select plants, emphasis should be on long-term rather than early survival and growth.

Resistance to disease and insect damage is an important consideration in selection of plants. Clearly, mixed stands of plants which act as alternate hosts for diseases should not be planted together. The desirability of the products produced on the land should be a factor in selection as well as the desired objectives of the recovery effort. For example, amur honeysuckle (Lanicera maackii) is a shrub useful for wildlife food since it retains its fruit during the winter. This plant might be a good choice for use in the northeastern U.S. when the objective is to encourage wildlife to invade the area. (Ruffner and Steiner, 1973). The plants should be suited both to planting site and local climate (Limstrom, 1964).

In selecting plants, thought should be given to the availability of seeds or seedlings. Locally produced plant materials are best as they will have undergone the selective pressures of the area. Not only quantity but quality of plant materials have to be considered. Quality will be discussed in the next section, Propagation.

The observation of surrounding plant communities in the area of fugitive dust sources can doubtless afford valuable information to be used in selecting one or more species for planting. Native vegetation offers an excellent starting point for species selection because all indigenous vegetation is, in fact, a bio-indicator, predicting the type of conditions that will probably eventually prevail at the fugitive dust source. Attention should be given to those species which "volunteer" on the site to be planted.

If site conditions will allow, the site may be put into immediate agricultural or forest production. Often this may require extensive amelioration activities (e.g., grading to lessen slope, liming to increase pH, and amendments of fertilizer and organic material). In such a case, crops or forest tree species similar to those used in the locality will probably be best.

Some plants have certain anatomic features which make them more valuable for the stabilization of land than others. Dense needles or leaves help create a barrier to air movement through a stand of plants. Dense branching or multiple stems near the ground will slow wind movement close to the ground where soil could be picked up. Soil can be held effectively in place by dense growths of fibrous roots near the surface of the ground. Some plants which grow on steep slopes exhibit a root phenomenon called "edaphoecotropism". Stated simply, the roots curve so as to grow straight into a bank or cliff. These plants are of great importance in the anchoring of soil on slopes (Vanicek, 1973).

Plants should be selected to meet the specific needs of an area. For example, plants with tough leaves, large root systems, and low water requirements will do best in arid areas.

At times plants may be chosen which can improve iste conditions. For instance, legumes such as black locust (*Robinia pseudoacacia*) may increase soil nitrogen levels by nitrogen fixation through microbial associations. Other plants may simply increase the organic matter in the soil through primary production. Certain plants may be selected as nurse crops or companion crops. These crops contribute to the growth of other species, and it is best to use less competitive species as companion crops since any combination of species will be in competition for essential materials. For example, although black locust is a recommended legume for some plantings, it was found to be too competitive with black walnut (*Juglans nigra*) in reclamation of strip mined land in Kansas (Seidel and Brinkman, 1962).

The rapidity with which a given site is covered is important. Usually this means that grasses or grass-legume combinations should be employed initially due to their quick establishment and spreading. Once the surface is stabilized, slower growing trees may be planted. Trees and shrubs are especially desirable, not only from economic and aesthetic standpoints, but because they are deeply rooted and will not be as easily uprooted by water erosion as herbaceous species. This need for trees has been recognized in reclamation work at Copperhill, Tennessee (Marx, 1975).

May (1971) has listed the following factors as affecting planting, survival, and growth of plants used to revegetate strip mined areas: soil texture, soil reaction, length and steepness of slope, erodibility, soil moisture, soil temperature, mineralogy of the spoil material, and nutrient availability. Each of these is crucial in the choice of a plant material. He points out that the traditional approach to species selection has been "trial and error" and that this has resulted in many failures. He further states that preliminary screening of species and testing of soil amendments to be used in revegetation projects has proven useful (May 1975). These tests provide "ball park" type data for use in the field.

It has been found that using more than one variety or clone of a species in revegetating efforts for each site enhances the chances of success. This is true for hybrid poplar (Populus spp.) where 25 or more clones are used on a given site (Kendig, 1968). This provides for better and more complete site adaptation.

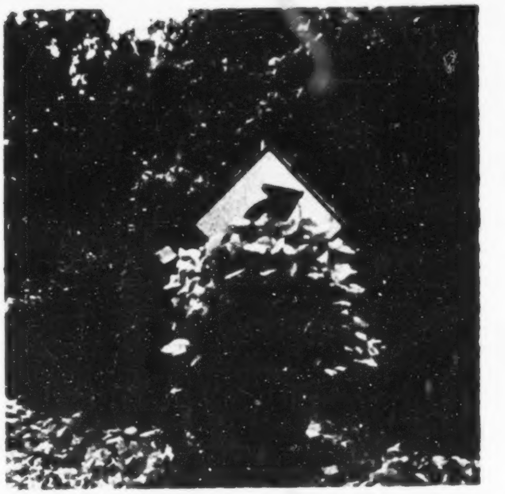
Plant species which are suspected of having the potential of becoming forest or agricultural pests should be avoided. Too often plant species become widespread before their ecological significance is realized. Two excellent examples of this are kudzu (Pueraria thunbegiana) and honeysuckle (Lonicera spp.), both of which were introduced from other continents and have been used in erosion control. Each became pests in the Southeast within a few years. Figure 14 summarizes the popular image of Kudzu at present.

Selection may be based on some special plant characteristics. The plant may have a high tolerance for low pH, drought, high metal levels, or other environmental factors.

However, the discovery of an "ideal" plant for harsh conditions is most improbable (Berry, 1975). Any plant will survive until some maximum limit of its tolerances is exceeded. This maximum limit can be exceeded only once. But it is not enough that the plant simply survive; it must grow and reproduce. If a suitable environment can be continuously provided, the number of species which can be used successfully will increase.

Kudzu: It Won't Give Up

Imported From Japan, Kudzu Thrives In North Carolina



Seasonal Sign

Somewhere behind this healthy crop of kudzu, a troublesome vine that grows with amazing speed, there's a highway sign that tells you the rural paved road in Caswell County curves to the right. Kudzu, a cussing word for many Tar Heels, grows especially fast in hot weather and swallows up telephone poles and trees. Story on 5B.

(Photo By Pat Bailey)

By JACK ADAMS
Herald State Editor

RALEIGH — A dairy farmer in Rutherford County is so enthusiastic about North Carolina's fastest-growing weed that he has KUDZU on his personalized automobile tag.

But the farmer, who grows kudzu as forage for his cattle, is the exception.

Most Tar Heels pronounce the weed as if they're trying to spit dirt out of their mouths.

The rampaging legeume has spawned an incalculable number of yarns — even stories of whole forests being swallowed up in a tangle of vines.

Mostly exaggerations, said Hall Campbell of Raleigh of the Soil Conservation Service, which used to raise kudzu in a nursery at the University of North Carolina at Chapel Hill.

"It's been overly kicked around," said Campbell, who contends that kudzu has not killed nearly so many trees as people claim.

Kudzu is an Asiatic weed that was first brought to America in the late 1800s and used as a porch vine.

Later, someone got the idea to use it for erosion control, particularly along highways, and North Carolina began buying kudzu seed by the bushels from the Japanese.

The seed was sown along road banks and in areas of high erosion from the coast to the mountains. Importing more seed became impossible during World War II, but the damage had been done. Kudzu has continued to spread without inhibition.

Dr. Doug Worsham, a weed specialist at North Carolina State University, said many complaints are referred to him from people who want to get rid of the weed.

About the best method of control is to use a chemical brush killer that, unfortunately, also kills everything else, including trees. Worsham says it usually takes four or five applications at a cost of $10 to $15 an acre to put an end to the weed.

Kudzu is hearty and grows in good and bad soil alike. The speed at which it grows is amazing.

Worsham pointed out that a plant could be at the base of a telephone pole at the beginning of a 60-day growing season and cover the pole at the end of the season.

Maybe tales of tree killing are exaggerated, but Worsham says it does in fact kill many.

Worsham said the amount of kudzu acreage is unknown. In 1946, an estimated 400,000 acres in the Southeast were covered with kudzu, and, in spite of efforts to kill the weed, Worsham suspects that it is holding its own.

Harold Singletary, plant pest chief for the state Department of Agriculture, said many farmers are waging an uphill battle against kudzu.

"I've seen entire fields that are uncultivatable because of kudzu," he said. "In locations where it gets out of hand, it can get into a forest and kill the trees."

The Highway Division of the state Department of Transportation has a policy of removing kudzu from highway rights of way, but only if adjoining property owners agree to pay to have it removed from their land.

If adjacent property owners don't go along with chemical control programs, the highway division just mows the weed and chops it back to keep it from creating safety hazards.

But many times the weed outraces the mowers, and highway signs get swallowed up in a tangle of broad-leafed vines.

Figure 14. Kudzu: It Won't Give Up (from the Durham Morning Herald, August 25, 1975).

If resources permit, a genetic screening program may be carried out to select desirable species or varieties. For instance, spoil samples may be seeded at heavy rates either in place or in the greenhouse and surviving plants used as seed sources for revegetation. Time and expense are the major drawbacks but where a large area is to be planted, testing may be well worth the expenditure.

In the process of selecting species, seeking the advice of personnel with state agricultural extension services, the Soil Conservation Service, or the Forestry Service is always in order (Appendix C). These scientists are carrying out work which may relate to the problem at hand and part of the mission of many of these agencies is to assist the public with problems related to their respective area of expertise.

6.1.2 Propagation

The success or failure of plantings for the control of fugitive dust emissions depends largely on the method selected for propagation and/or maintenance of seedlings after planting. Propagation includes the type of plant reproductive system used (e.g., seeds, seedlings, or unrooted cuttings) as well as planting techniques. In agricultural practice, the inherent reproductive capacities of plants are exploited. For example, plants which form seeds prolifically and whose seeds have high rates of germination will generally be planted in the field as seed rather than seedlings.

6.1.2.1 Background -- Plants may be divided on the basis of three distinct life cycles--annual, biennial, and perennial. The annual plant's entire life processes, from germination to production and dissemination of seeds, take place in a single growing season. The plant then dies. Summer annuals require warm climates; they germinate at the onset of spring; and flowering and seed formation occurs during long summer days with high temperatures. Winter annuals grow where winters are mild and moist. Germination takes place in fall or winter with flowers and seed being set in late winter or spring. They die in summer.

Biennial species have a life cycle that spans two years. They also have a chilling requirement (Hartmann and Kester, 1975). Plants come up from seed in summer or fall and remain in a vegetative state the first growing season. A lower ring of leaves, a rosette, is formed during the first season by many biennial plants. Dormancy occurs in winter. The winter chilling stimulates transition to the reproductive stage. During the second growing season the plant flowers and seeds form, followed by death of the plant.

Perennials live from year to year and generally display an annual reproductive cycle. They may be either herbaceous or woody. Above ground portions of herbaceous species die in winter within temperate zones. They persist during dormant periods by specialized underground roots or stems. Woody perennials continue to increase in size each year by growing at shoot and root tips and by lateral growth. Cambial regions (areas where cell division is occurring) exist in these areas.

Artificial plant propagation is based on the natural reproductive capabilities of plants. There are two developmental cycles of plant reproduction; these are sexual (by seed formation) and asexual or vegetative multiplication (by runners, rhizomes, or horizontal roots).

Fertilization is the essential feature of the sexual cycle which utlimately produces seeds. Male and female sex cells contained in the flowers form the zygote which becomes the embryo in the mature seed. This embryo gives rise to the adult plant when the seed germinates. Flowers are composed of distinct organs with specialized functions. The stamens form pollen grains which contain the male sex cells. Female sex cells are contained in the enlarged lower portion of the pistil. Fertilization occurs when pollen grains are deposited on the pistil after which seed formation begins. Sexual reproduction can result in variation among plants and is the basis of plant breeding and genetic selection to obtain desired qualities in plants. This variation may also become a problem since the genetic make-up of subsequent generations may vary. This often leads to the use of vegetative propagation to maintain pure lines.

Natural asexual reproduction is generally limited to perennials. Structures which enable this type of reproduction to occur include prostrate aerial stems (stolons), underground stems (rhizomes), and horizontal roots. Virtually every organ of the plant is capable of vegetative reproduction. Many techniques for this type of propagation have been devised. Probably the most widely used method is that of cuttings. Stem cuttings are generally employed although some plants do not root well. Hormones may be used to induce rooting. The most common methods of vegetative propagation are plugging, sodding, sprigging, and stolonizing.

Unrooted stem cuttings called "sticks" have been used in establishing hybrid poplar on strip mined areas (Kendig, 1968). About 50 percent of those planted survive the first year and around 95 percent of these survive through the second year.

Vegetative plugging of giant burmudagrass has been employed to stabilize copper mine tailings (Day and Ludeke, 1973). In this procedure, small pieces of sod are planted.

Vegetative propagation has an important function in maintaining natural land forms. Hence it is very significant in considering the use of plants to control fugitive dust originating from mineral surfaces. Vegetative reproduction accounts for the ability of plants to spread over vast areas as dense growths. This rapid spreading makes these plants useful in soil stabilization and enables them to invade shifting soil (e.g., sand dunes). This capacity also enables certain plants such as grasses to become dominant in meadows and prairies.

The two main advantages of using vegetative propagation are speed in producing new plants and the production of plants genetically like the parent stock.

Offspring of a single plant are known as a clone. The perennial legume, kudzu, is propagated as clones (Wilson and Loomis, 1962). It was widely used for erosion control in the southern states, but has rapidly become a noxious weed (Figure 14). Ground cover is provided by dense foliage in summer and in winter bare vines and fallen leaves provide protection against erosion. Runners grow over the soil surface, rooting at the nodes. Buds form above the roots which enlarge to form crowns. Over winter vines which connect the crowns die and next season each crown forms a new plant. Crowns which are two years old are used to plant new areas. The plant produces few seed and germination is poor so that propagation must be by asexual rather than sexual reproduction.

6.1.2.2 Planting Technique -- Whether to use seeds or young plants is an important decision. Site characteristics will often dictate selection. Where the site is inaccessible to planting crews, direct seeding from aircraft may have to be used. If the site is very dry, seedlings may be best. The expense of the operation is important but must be evaluated in terms of the expected long-term success of the revegetation effort.

Direct seeding has been discussed by Chan (1974). He reports that the success of seeding is related directly to plant species, environmental conditions, and the skill of the planting crew in using proper techniques. Native seeds are considered best and attention should be given to seed size, dormancy, and any necessary seed treatment. Seed should be collected and stored properly, then planted at the proper time. Other factors to be considered are planting depth, fertilizer addition, weed control, animal browsing, and diseases such as damping off (fungal diseases of germinating seeds). Advantages of direct seeding are quicker and greater availability of plant material, ease in logistics and planting, and reduced maintenance because plants are naturally conditioned.

Brown (1971) has reported on both the direct seeding of black locust and on the use of seedlings on vast areas in West Virginia. The following data were given:

	Direct Seeded	Nursery Grown Seedlings
Success	20	75
Intermediate	50	19
Failure	30	6

The low rate of success with seeding was due largely to lack of adequate moisture. The radicle (young root) emerging from the seed must penetrate the surface rapidly enough to keep pace with soil drying. The poor texture of many spoils coupled with compaction which impedes penetration slows this vital process. High surface temperatures due often to dark spoil colors may desiccate freshly germinated seedlings. Competion with other plants that may be present is also a problem. Success may be enhanced by seed treatments, seedbed preparation, covering seed, and using mulch. The cost of seeding properly may exceed the cost of using seedlings. Establishing ground cover by seeding will require 1 to 2 years under excellent condition but usually will take 5 or more years.

Use of seedlings circumvents some of the problems of direct seeding. Use of containerized stock is superior to bare-rooted seedlings, especially under harsh conditions (Berry, 1975).

In fairly hospitable environments where severe erosion is not an immediate threat, seeds may be the most feasible and economical method of producing ground cover. However, under more harsh conditions seedlings may be necessary because at least some erosion protection will be available immediately upon planting. Techniques used for culture (i.e., fertilizers, irrigation, mulches, organic amendments, etc.) will be especially important. Economics will have to be balanced with providing an adequate environment for plant growth.

The choice among seed, bare-rooted seedling, or containerized plant will have to be based on the environmental characteristics of a given site. Availability and cost of plant material will also need to be considered. Propagation requirements may include certain subtle factors--periodicity of light, cold period, etc.

Viable high quality seeds should be used in a quantity sufficient to ensure an adequate ground cover. Various methods are available for testing seed viability but tested seed are commercially available. These are labelled in several ways to indicate pure live seed (PLS). Certified seed indicates that the number of extraneous weed seeds per unit of seed has been held to a minimum. The amount of seed planted will vary with several factors, including size of the seed and method of planting. When small seeds are used, fewer pounds per acre will be required than when larger seeds are used. Broadcasting requires approximately twice as many seed as is needed when the seeds are planted by drilling. Recent reclamation experiments in Kentucky and Virginia indicate the feasibility of planting mountainous terrain by use of airplanes, (Coal Age, 1968). South and west facing slopes require about twice the number of seeds as north and east facing slopes and poor sites require proportionately more seed (Cook et al., 1974). In the Appalachian region, almost any time except between November 1 and March 1 is suitable (Vogel, 1974).

The special needs of particular seeds that ensure germination are imporatant. Some seeds with thick coats require scarification or scratching of the seed coats to ensure germination at the desired time. Some machines are available for doing this. Other seeds require a cold treatment prior to germination. These types, if chosen, can be planted before winter to ensure spring germination or can be purchased already cold treated if spring planting is desirable (Hartman and Kester, 1959).

Soil tests will reveal the peculiarities of the site and make the addition of soil modifiers more meaningful. Lime and fertilizers are the two main types of soil additives that need to be considered. Application of nitrogen before planting often increases weed growth and results in acute competition with the desired species for moisture and nutrients (Cook, et al., 1974). Some authors recommend applying nitrogen after the first growing season. Legumes and nitrogen-fixing plants may be planted along with other species to ensure a constant supply of nitrogen to the site so that commercial fertilizer need not be applied so frequently (Magnuson, 1969).

Spreading mulch on recently disturbed sites is a common practice when a grass cover is desired. However, mulch is expensive and is not always necessary to establish vegetation. Mulches have their greatest utility in harsh sites that are to be seeded. They serve to minimize erosion and reduce water loss from the soil. In arid areas, this water conservation results in a larger number of surviving seedlings.

There are several types of mulch: wood fiber, straw-asphalt, and soil-anchored mulch. Wood fiber is the most effective of the three and should be applied at the rate of 0.1 to 0.3 kg/m^2 (1000 to 3000 pounds per acre) depending on individual sites (Kay, 1974).

Hydroseeding is a method of establishing seedlings on slopes which are too steep to be planted by any other method (Currier, 1971). Water, seed, mulch, and fertilizer are agitated in a tank and sprayed through a nozzle over the area to be planted. It is effective up to 24.4 m (80 feet) from the sprayer.

A two-step system for revegetation of surface mine spoils has been used successfully (Jones, et al., 1975). First a fast growing ground cover (e.g., rye (Secale cereale, L.)) is established to minimize erosion.

This is then chemically killed and a more persistent crop is planted. For this, clovers with interseeded grasses were excellent. This method furnishes the benefits of mulch but greatly reduces its costs.

Some genetic selection might well prove useful. Seeds or seedlings from a particular site could be harvested for use on another part of the same site or a similar site in the same general locality. Selection might also be performed artificially by using plants grown in nurseries with conditions similar to those of the site to be covered. For example, seedbeds using soil material similar to that at the site could be established, preferably near the site. Healthy seedlings selected from these would be used for planting.

In many instances, it is desirable not only for the species planted to reproduce within an area, but also for the area to be invaded by various volunteer vegetation.

Patterns of planting also become important for fugitive dust control. In some flat delta areas, it has been found that planting circular rows of crops is far superior to conventional straight rows in preventing damage by win[illegible] low dust abrasion. Straight rows provide long channels where wind velocity may build up, resulting in severe crop damage by "sand blasting". In light of this, the design of plantings for fugitive dust control should be planned so as to derive maximum wind control from them. Perhaps random spacing would be better than rows although initial planting and culture would be more difficult. Mixed species and different plant sizes could be quite useful. Compatible reproduction by mixed plantings should also be taken into account. Here interspecific competition becomes of utmost concern.

A complete discussion of the principles and practices of plant propagation has recently been given by Hartmann and Kester (1975).

6.1.2.3 Maintenance -- Methods of culture during propagation are important factors in ensuring survival. For instance, regularity of irrigation will be most important. When irrigated, plants should generally be deep watered to encourage deep root formation. Irrigation should be infrequent if drought is anticipated so as to condition and harden plants.

According to Vande Linde (1971), one of the principal causes of failures in efforts to stabilize areas that have been strip mined has been a reliance on techniques used in forestry. Obviously, planting trees on 6-feet by 7-feet (1.8 x 2.1 m) centers, as is used in forestry, cannot readily control erosion. The same is true of planting procedures ordinary used for agricultural row crops. Therefore, special techniques must be devised in planting barren areas for stabilization.

6.1.3 Succession

The principles of ecological succession are important to the establishment of plant covers over areas which are sources of fugitive dust. This succession involves the development of ecosystems. The ecosystem is a unit of biological organization which consists of the organisms of a particular area (i.e., community): 1) only those species can be present which exist in that particular part of the world, and which are able to reach the particular spot; 2) only those can be present which are able to exist under the given conditions of life and in competition with the other species present; and 3) in many communities certain species can survive only in the presence of others and the environment they create (Willis, 1973).

Ecological succession is an orderly process by which ecosystems evolve, replacing one another in time. Where plant groups invade a barren area (primary succession), replacement by other plant groups (secondary succession) generally follows.

Many natural succession events are well studied. Such information may prove useful in approaching problems associated with vegetation piles of material from which airborne dusts may originate. For vegetative covers to be feasible in particulate air pollution control, they must be established within a short time frame. What we are considering is a kind of man-induced flashback to an unweathered primeval landscape with no plants. The idea then becomes one of compressing the time for vegetation to invade naturally, perhaps several decades, into a much shorter period. This speeding up of events is done by modifying surface soils to render them more suitable for plantings.

Simply to grow plants is not enough if a permanent ground cover is to be provided. Creating a self-sustaining plant community is the ultimate objective (James, 1966). It is encouraging to note that artificial plants of native species have succeeded in forming communities indistinguishable from natural woodland (Willis, 1973). Toward accomplishing this objective, studies of naturally barren environments (e.g., volcanic areas and beach sites) may provide insights that are applicable to the problem of establishing vegetative covers on fugitive dust sources. Ecological investigations of plant succession on the sources themselves may also be of benefit.

6.1.3.1 Natural Succession on Sources of Natural Origin -- Einarsson (1973) has reported on the invasion of terrestrial plants on the newly formed (1963) volcanic island, Surtsey, near Iceland. Plant material was observed less than a year after eruption of the volcano began. Plant parts of 30 species were identified. In general they were plants which commonly grew on the coasts and cliffs of islands. Of the 6 species observed growing, most of them grew along the high-water mark of the coasts, but some were as far as 30 meters inland. Nine species of mosses were found on the volcanic island. This fact is not surprising because mosses constitute a major vegetative cover on nearby Iceland. Certain species of the mosses are also found on brown-coal dust, and one, *Funaria hygrometrica*, is the first colonizer of pulverized fuel ash.

The beach environment somewhat resembles certain tailings piles (which may be fugitive dust sources) in its instability, infertility, light intensity, texture, and water relations. However, there is one major difference. According to Oosting and Billings (1942), the major force affecting plant growth and form on a seacoast is intensity of salt spray. The chloride ion in the spray is the toxic agent which may inhibit growth.

Many beach species display adaptions such as thick cuticles, extensive root systems, and folding leaves which enable them to survive under the harsh extremes of the coastal environment. Some other plants have life cycles which enable them to survive. They exist as seeds during stormy seasons seasons when amounts of salt spray are high. A peculiar form of adoption in seaoats (*Uniola paniculata*, L.) is that of rapid stem elongation; this keeps it above the sands that tend to pile up on the crest of dunes.

Succession on dunes is slow because of the nature of sand which in general holds little moisture and is low in nutrients. Studies of such succession on Lake Michigan dunes are available (Odum, 1963). Succession has followed as the lake has receded over the years. Pioneer communities consist of a few grasses, and willow, cherry, and cottonwood trees which are followed by forest communities. The forest stages are: Jack pine forest, black oak dry forest, and oak and oak-hickory moist forest. The climax (final) stage is beech-maple forest on deep humus soil which had its beginning as infertile sand. Early successional stages may be stopped if sands are rapidly shifted by wind.

Two distinct types of pioneer communities have been described in sand dune succession in England (Eyre, 1968). The first is dominated by sea couchgrass (Agropyron junecum) which invades the base of dunes and occurs below the highest tide level. Succulents including sea sandwort (Arenaria peploides), sea rocket (Cakile maritima), prickly saltwort (Salsola kali) and orache (Atriplex spp.) are common in this community. They entrap sand and contribute to dune formation. The second community type occurs above the highest tide level and is dominated by marram grass (Ammophilia arenaria). Rhizomes of this plant enable it to grow vertically or laterally to keep up with dune development. It has strong stabilizing effect on the dune. Once the dune is stable, groups of rosette plants such as ragwort (Senecio jacobaea), hawkweed (Hieracium umbellatum) and thistles (Circium spp.) can invade. Survival of these, however, is dependent on the marram grass which prevents massive shifts of the dune sands. Generally dune communities remain open and this allows some surface mobility of the sand. In the third or fourth stages of succession, sand fescue (Festuca rubra var. arenaria) can form a turf over the surface which eventually eliminates tufts of marram grass.

6.1.3.2 Natural Succession on Man-made Mineral Waste Heaps -- It is customary for botanists to work on natural vegetation and to ignore that which occurs in man-made hibitats (Bradshaw, 1970). However, some studies of natural plant succession of barren surfaces created by man do exist and these may provide valuable insights into what species and practices should be used in revegetation programs. The important feature of plant populations that do occur on mine spoils is that they grow vigorously while members of the same species from ordinary populations may not survive at all. They have been naturally selected for the harsh environment.

Factors which influence plant colonization of silver, lead, and zinc mine waste in Utah have been studied (Alvarez, *et al.*, 1974). Soil temperature and texture and levels of phosphorus and calcium differed significantly among sites stratified according to plant cover and floristic diversity. Preferences for soil temperature and levels of phosphorus and calcium were seen. Soil phosphorus correlated strongly with the density of vegetative cover. Phosphorus differences were related to soil parent material. The authors note that, even though mine dumps have a superficial similarity, they vary tremendously in available nutrients, color, texture, and other factors and, hence, cannot be treated as one environmental type. In this study, mine wastes in three adjacent canyons were quite different in their ability to support plant life. It was clear from the variability of a given site that a mixture of species would very likely be superior to a single species in artificial revegetation of such areas. Knowledge about factors which govern natural colonization of mine dumps will lead to more effective methods for revegetating these harsh sites.

Plant populations which invade mining and smelting waste have been investigated by Bradshaw (1970) in England. From his work, the use of tolerant species appears to be the most promising approach for use on lead, zinc, and copper smelter wastes where lack of nutrients and metal toxicity are a limitation. Plant nutrients may be conveniently applied at low costs. However, nothing short of covering these tailings with soil ameliorate the toxicity problem since no method of removal is known. Leaching would require tens of thousands of years and some wastes actually become more toxic as breakdown occurs, releasing more metallic compounds. Calcium addition has a slight ameliorative effect, and phosphate can lock up metals but the quantity needed is impractical.

The evolution of metal tolerant species on metal tailings has been observed. Among them are *Plantago laceolata*, *Agrostis stolonifera*, and *Festuca rubra* (Bradshaw, *et al.*, 1965). Tolerant populations of various species especially *Agrostis* and *Festuca* have been used successfully on smelter tailings in the Swansea Valley of England (Smith and Bradshaw, 1970). Amendments of slow release fertilizer enhanced growth significantly.

Antonovics (1975) has pointed out that on sites where metal has been mined in North Carolina, vegetation encroaches from the site's edge. He suggests that this encroachment is due not so much to nearness of seed sources or to suitable microclimates set up by neighboring vegetation, but rather to a kind of "chelation" (i.e., tying up) of toxic metals by organics from litter produced by peripheral vegetation. Once levels are below lethal concentrations, plants begin to invade.

The idea of metal chelation is supported by Carroll (1970). She states that metallic cations are absorbed by organic ring compounds in the soil. In certain cases, it may decrease amounts of metals to non-toxic levels. This may be one of the important roles played by soil humus.

Plant colonization on wastes from anthracite mines in Pennsylvania has been investigated by Schramm (1966). He reports that refuse (shales separated from coal) is colonized extremely sparingly by woody plants and that herbaceous types are almost completely absent. Woody species that do establish grow reasonably well. Sludge (material washed from coal and purged to settling basins) is not colonized at all. Slope, soil temperature extremes, and distance from natural vegetation were significant in determining rates of colonization. Growth and development found to play a minor role in the sterility of anthracite wastes. Addition of nitrogen without other major nutrients was found to contribute to improved plant growth. Overall, nitrogen-fixing plants and certain ectomycorrhizal species* were the only successful pioneer invaders of the nitrogen-deficient wastes. Therefore, these two types would be useful in revegetation efforts.

Sturm (1973) identified naturally invading plant species on strip mine spoils in West Virginia. His study showed that invasion was correlated with spoil pH; there was a distinct line between vegetated and barren areas. No plants grew below pH 3.7 and no barren sites existed above pH 3.7. Sites without plants were significantly lower in nutrient levels. Red maple (Acer rubrum) was the most tolerant of low pH and low nutrient levels. Poverty grass (Danthonia spicata) was the most tolerant grass species. Other species included false redtop (Triodia flava), broom edge (Andropogon virginicus), deertongue (Panicum clandestinum) and black birch (Betula nigra). Results indicated that proper liming and fertilization could bring these mining spoils into productive states.

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*Ectomycorrhizal species are plants whose roots form mycorrhizal associations in which fungal hyphae form compact mantles on root surfaces. Mycelial strands extend inward between root cells and outward into the soil.

In a study of coal mine spoils, Kohnke (1950) found that more favorable soil conditions for plant growth exists in "troughs" of strip mined land. Here abundant water has leached free acid and lime fragments have been deposited thus raising the pH.

Byrnes and Miller (1977) have reported on the natural revegetation of surface-mined coal lands in southern Indiana. Their study revealed that plant invasion begins the first year after mining in more favorable spoils, especially in "troughs" as Kohnke reported. Some toxic patches of overburden remained devoid of plants up to 45 years. Soil pH lower than 3.5 and specific conductance (an indication of the amount of soluble salts) above 2 mmhos/cm appeared to adversely affect vegetation and limited its encroachment. In this study, it was noted that the disturbed sites invaded by natural vegetation did not resemble surrounding undisturbed sites until [illegible] years after mining. Lists of preponderant species are provided. Trees had poor form and were of different ages; therefore, it was concluded that timber production would be poor. About [illegible] percent of the species seen were classified as preferred by wildlife.

Limstrom (1960) has also concluded that adequate stands of forest trees for commercial timber production are very unlikely to establish naturally in areas disturbed by mining. He gives several reasons why this is true. Good seed sources must be present; this is not the case for most strip mined areas except perhaps at the edges. Conditions on spoil banks are not conducive to the lodging and germinating of seeds. Erosion often causes seeds to be deposited at bottoms between ridges so this is where most volunteer vegetation is found. Thus, strong competition could occur on these lower areas with no competition on slopes.

In programs to establish forests on strip mined lands, naturally occurring vegetation can be both harmful and beneficial (Limstrom, 1960). Volunteer plants can protect young forest species from drying winds, improve conditions of the soil, and reduce losses from erosion. However, they can also compete with the trees which have been planted. Dense ground covers reduce survival of many pines and some hardwoods. Overhead cover is at times favorable to early survival and growth but may be a hinderance in later stages.

Wilker (1972) has cited a case where natural vegetation may produce an adverse effect. The plant is sagebrush (Artemisia spp.) whose feeder roots prohibit understory growth, often leaving the surface bare and susceptible to erosion.

It is interesting to note that cattails (Typha latifolia, L.) have been observed to thrive in pools of mine water at pH 2.5 and that ragweed (Ambrosia elation, L.) can grow well on spoil material below pH 3.0 (Kohnke, 1950).

Volunteer vegetation that appears on land stripped for coal come predominantly from airborne seeds or from portions of original topsoil left at the surface. Practical foresters have used the appearance of vegetation on spoils as in indication that the area may be safely planted with trees.

Succession in plant communities on coal mine dumps in England has been studied (Down, 1973). Seventy-three species of vascular plants were observed. Hemicryptophytes and therophytes comprised over 90 percent of the pioneer flora. Hemicrytophytes are plants that produce buds just beneath or at the soil surface; they grow as dense tufts. Therophytes complete their life cycle from seed in one growing season; they survive unfavorable periods as seed or in a vegetative form, often as a short stem with a rosette of leaves (Willis, 1973). These two plant forms are well-suited to open, exposed, and unstable habitats such as are provided by mineral waste dumps (Down, 1973). Certain attributes of species which have rosette forms add to their capacity to survive harsh conditions. Long taproots (up to 20 cm) provide positive anchorage on unstable surfaces and deliver water from lower depths. The rosette of basal leaves tends to reduce the range of temperature fluctuation around the plant and reduces water loss from the soil beneath it.

The author points out that species similar to these pioneer species should be considered for ground covers on coal mine wastes. Most effort, thus far, has concentrated on the artificial planting of grasses and/or legumes.

Biological succession at excavated mine sites of the Cologne Lignite District in West Germany was studied by Bauer (1973). Habitats included gravel slopes, gravel plains, reclaimed fields, coal-dust areas, depressions and lakes. Despite harsh extremes of soil and climate, spontaneous rapid colonization by various plants and animals was observed. Areas were reported to change in appearance from desert like to grass steppe and then gradually to savanna like. Then trees and shrubs became established. Successful plant invaders displayed the ability to germinate rapidly and had very low demands on the environment. Pioneer vegetation was strongly influenced by the microclimate of mine wastes. Plants which established were found to be chance combinations of species without regard to natural associations. Until a closed canopy begins to form and competition starts, pioneer types (tufts or grasses, stolons, and rosettes) remain. Because of the variety of habitats formed by mining activity, such areas support more plant species and associations than the original and undisturbed sites. From studies of natural plant succession, Bauer and Darmer (1969) formulated the following principles for reclamation of areas disturbed by mining:

1) Gravel dumps should not stand isolated and should not be higher than 30 meters. The general inclination should not be steeper than 1:5.

2) For agricultural reclamation, a loess cover at least 2 m deep is necessary.

3) Extreme microclimatic conditions must be modified and a balanced bioclimate developed through formation of a suitable relief and establishment of shelterbelts.

4) Water controls productivity; regulated irrigation and drainage, shelterbelts, and lakes balance the humidity of air and soil.

5) Because of the extreme ecological conditions, trees must be planted at once and fields must be seeded promptly while the soil is still loose and well aerated. One should not wait for weathering of the soil material or formation of humus because fine-textured material may be blown or washed away. At any rate, the soil becomes more dense during any period that reclamation is delayed.

6) The more varied the plant cover and the better ecologically adapted it is, the better are the opportunities for animal establishment.

7) In addition, the formerly disturbed areas may become useful for recreation; the varied habitats of the forest-field-lake landscape offer ideal conditions for this use.

6.2 ENVIRONMENTAL FACTORS

Plant life is dependent on many factors which interact to produce a habitat in which growth and reproduction can occur. The habitat is the sum total of all environmental factors which are effective in determining the existence of a plant community in that place (Willits, 1973).

There are three reasons why a plant grows in a given habitat: 1) the plant or some of its progenitors happened to get to the location, 2) the plant has the capacity to survive, grow, and reproduce under the existing conditions, and 3) the plant has not been crowded out by other plants or eliminated by animals (Salisbury and Ross, 1969).

Plants are dynamic organisms and are sensitive to continuously shifting environmental factors. Environment not only influences the individual plant body but also governs to a large extent the distribution of plant groups on the earth. For any given species, there are limits under which it can grow and reproduce. Certain plants display broad tolerance ranges while others grow only within narrow limits. One of the most unique features of plant life, however, is the occurrence under so many conditions and at such harsh extremes. The plant is in a dynamic balance between its physiological and structural features, and its immediate surrounding.

Several major sets of conditions interact to form the environment. These are geographic, geologic (pedologic and edaphic), climatic (e.g., light, precipitation, temperature, and wind), atmospheric, and biotic. The control of these factors is the dominating task of agriculture. And it is controlling or buffering these factors that will enhance the survival of plantings which are made for the purpose of suppressing fugitive dust emission. The following is a discussion of these key environmental factors, with special attention being given to those which are of concern in the planting of surfaces from which fugitive dust arises.

6.2.1 Geographic

Vegetation is affected by those geographic factors which influence climate and weather patterns. The proximity of mountains or large bodies of water plays a major role in the determination of climatic characteristics.

For example, mountain ranges along a seacoast may produce moist forests on the seaward side with desert on the inland side. Lesser relief patterns of land affect vegetation through their influence on wind velocity and direction, local rainfall, and seasonal temperature. Ocean currents contribute heavily to the regulation of climate and, hence, to the distribution of terrestrial flora (Bidwell, 1974).

Altitude and latitude are particularly important factors to be considered in the choice of plant species for the area in question. These govern solar insolation and temperature which exert strong effects on many other conditions.

The location of the site to be covered with vegetation is important. It may dictate the methods of vegetative reclamation that should be used. For example, in a chiefly agricultural region, planting materials will probably be readily available whereas in other areas these materials may have to be brought in, thus greatly increasing costs. It may be that plant species used for ground cover to prevent general erosion in a given area would be useful in covering dusty ground surfaces in the same area. Air quality of a specific locality should be considered if there is reason to suspect that it may damage planted species. The proximity of receptors of fugitive dust may determine priorities for vegetating surfaces which are sources.

6.2.2 Geologic

The geologic processes of a region determine its soil type and produce its topographic relief. Perhaps the most important aspect of geological phenomena so far as plants are concerned is that of supplying parent material from which soils are derived. This parent material, usually bedrock, is extremely important in determining soil moisture relations, soil type, structure, and nutrition. The kind of soil plays a significant role in determining which plant species will grow on a given site.

Topography also influences factors affecting plant growth such as extremes of drought, cold, heat, and excess water (Bidwell, 1974). The topography of an area is also important as to slope inclination and slope length. If plants are to establish and thrive, topographic features must not exceed certain limits. Water erosion of soil becomes especially important in that plants may not be able to remain anchored. If topsoil is present, it may be lost during rain if slopes are too steep.

Since soil is the most important geologic factor, its origin and nature (pedology) and its relationship to plant life (edaphology) will be considered.

6.2.2.1 Pedologic -- Weathering of parent material by any particular combination of climate, vegetation, and relief progresses through a definite series of stages. At maturity (after many years) the soil which has been formed is in a state of dynamic equilibrium with the factors that have determined its course of development. Properties of soils have been discussed in Section 2 of this report.

The origin of the soil in question is important because it determines many of its final properties. In many cases where the site is a dust source, the ground material may be considered a virgin soil essentially unaltered by wind, water, or biotic factors. Predicting the course of soil change over a short period (i.e., a few years) will help in deciding if and how the ground material should be amended to enhance its capacity to support plant life.

Surface characteristics may be governed--especially in the case of mining activities--by stratifying different material types. For instance, topsoil should be stockpiled before and replaced after strip mining. In some cases, care could be taken to see that pyritic or other acid-forming minerals are buried deep enough so that they do not influence surface pH. In a given situation, there may be ways in which layers of such strata may be replaced to enhance the plant-soil environment rather than simply haphazardly replacing the material by the fastest and cheapest means possible.

In nature, physical, chemical, and biological agents act together to convert parent rock into soil. Soil development may be divided into four main stages: 1) mechanical weathering of rock into fragments of parent material, 2) chemical weathering of this parent material to form secondary minerals, 3) biochemical weathering accompanied by the accumulation of organic materials, 4) the maturation of the weathered materials over time into a fully developed soil (Pearson, 1967).

Physical processes break surfaces or rock masses into smaller and smaller fragments. Chemical reactions result in compositional changes within such material. Plants and animals contribute to both processes and add the organic component to the soil.

Physical agents (e.g., water, wind, ice, and gravity) affect disintegration of rock. Water and wind are functional through erosive actions of the load of cutting material they transport. Therefore, the effect is proportional to speed or force. Temperature effects are widespread. Rocks can be cracked by differential expansion and contraction, particularly when temperature changes are rapid. Temperature fluctuations are widest in arid regions and at high elevations where their effectiveness is shown in the coarse, angular soil particles that occur in these areas.

Chemical processes lead to increased solubility of soil components. This not only makes nutrients available for plants but renders them susceptible to leaching during rains. Oxidation (addition of oxygen) and hydration (addition of water) are common reactions and result in the softening of rock. Carbonation (uptake of carbon dioxide) yields the dissolving action of water. Innumerable other chemical reactions occur among minerals which contribute to the weathering that eventually forms soil (Oosting, 1956).

Living organisms are involved directly and indirectly in the soil forming process. Particles are broken up by eating and burrowing animals and by the pressure and prying action of roots. Animal activities result in mixing and transfer of differentially weathered materials. By-products of metabolism such as carbon dioxide and various organic materials enhance chemical reactions. Organic acids from decaying organic compounds are especially potent in dissolving mineral materials. The organic fraction of the soil which is so critical in water and nutrient relations is added by living organisms.

Some naturally occurring soils which develop from certain kinds of rock support very little plant life and are known as "barrens". Either essential nutrients are lacking or toxic concentrations of certain materials are present. These problems may also be presented by mine wastes from ore processing or from strip mine overburden. Severe nutrient imbalances that exist in these materials and excesses of heavy metals (e.g., lead, zinc, mercury, and copper) often combined with low pH are very unfavorable to plants (Daubenmire, 1974).

6.2.2.2 Edaphic -- Edaphic factors are those characteristics of soil which interact directly with plants, especially higher plants. Besides light and carbon dioxide, plants need soil with proper textural and chemical properties, and with adequate but not excessive moisture for growth. Optimum growth can only be attained if these needs are met. More specifically, plants are dependent on soil for mechanical support, nutrients, water, and oxygen for root respiration.

Soil characteristics are largely governed by the climate. For example, desert soils, which are very unlike soils of humid regions, may have actually been derived from identical parent material. The plant-soil relationship is reciprocal in nature. Soil characteristics are influenced by vegetative cover while the distribution of plants is in part determined by soil types.

Brady (1974) has given an in depth discussion of the nature and properties of soils. Practical and theoretical aspects are considered.

Areas which are sources of fugitive dust may present a number of edaphological problems. Amelioration of these problems is generally necessary before plants can be established.

Dean, et al. (1969) have noted that tailings from mineral processing area: 1) deficient in plant nutrients, 2) contain excessive levels of salts and heavy metal phytotoxicants, 3) contain unconsolidated sands which "sandblast" plants, and 4) lack normal microbial populations.

Edaphic problems associated with strip mining spoils include: 1) excess acidity, 2) low amounts or organic matter and nitrogen, 3) low phosphorus concentrations, 4) unsatisfactory moisture relations, and 5) toxic levels of certain elements.

Approaches that have been taken to solution of these problems are considered in Section 5.

Edaphic factors fall into the three major realms: physical, chemical, and biological. There are strong interactions among them, and each is more or less active in governing the character of the other two.

6.2.2.2.1 Physical -- The major physical properties of soil are texture, structure, porosity, and color. Secondary properties are water retention and movement, and aeration. These physical characteristics influence the soil's mechanical supporting strength, drainage, nutrient retention, and resistance to plant root penetration (Foth and Turk, 1962).

Texture refers to the relative proportions of various soil particle sizes, or more specifically to the relative amounts of sand, silt, and clay. A diagram of textural classification is given in Figure 3 of Section 4. Texture strongly influences soil water and air relationships. Since it determines the amount of surface area a given volume of soil particles will have, it is also very important in governing the rates and extents of chemical reactions. As soils are created, horizons which result usually differ in texture.

This texture profile can be beneficial or harmful to plant growth. Up to a certain level, increasing the content of clay in soil is desirable since water and nutrient holding capacities will be increased accordingly. This in turn reduces loss of nutrients by leaching since downward percolation of water is slowed. However, too much clay can form a clay pan (compacted layer) which can restrict the movement of water and air. In addition, root penetration can be hampered. Since infiltration of water is inhibited, runoff increases with accompanying increases in erosion. Sometimes altering the texture profile can help to control wind erosion (Foth and Turk, 1972). It has been observed that, where sandy surface soils are underlain by soil containing 20 to 40 percent clay, deep plowing served as an aid to halting wind erosion. Deep plowing had to be accompanied by other erosion control practices since alone it was not completely successful.

Soil structure refers to the aggregation of primary soil particles (i.e., sand, silt, or clay) into compound particles or clusters which are separated from adjoining clusters by surfaces of easy cleavage. Texture is modified by structure. Structure affects moisture and air relationships, plant nutrition, microbial activities, and root growth.

There are several forms of soil structure. These are single grains, massive, granular, platy, blocky, primatic, and puddled (i.e., "run together"). Structure develops during the soil formation process as parent material is weathered. Soil organisms produce agents which act as cement that aid in aggregate formation. Structure is important from the standpoint of 1) aeration, 2) water permeability and its relationship to runoff, 3) resistance to soil erosion, and 4) forming a good seedbed to initiate plant growth (Thompson and Troeh, 1973).

A good seedbed should provide a suitable environment for the seeds to an adequate depth. Enough small aggregates should contact the seed to supply sufficient moisture. There should be enough pore space to supply oxygen, first to the seed and then the seedling. Possibilities of the decomposition of organics by microorganisms, making nitrogen and other nutrients temporarily deficient, should be considered and eliminated.

There exists, on a research basis at least, the ability to produce soil structure. Soil conditioners are used; these are polymerized organic compounds which degrade very slowly such as Krilium, introduced in 1952. At present these products are too costly for general agricultural usage (Thompson and Troeh, 1973).

Porosity is simply the pore spaces within the soil bulk. These spaces are of importance because they are largely filled with water and air. These two important soil components are vital for plant growth. Movement is governed by the amount and size of pore space. Pore space is directly related to texture and structure.

Soil color is related to organic content, climate, drainage, and parent material. Color may be used to interpret various soil properties. For example, a drak colored soil may be high in organic matter. Soil color is particularly important to the heat balance of soil. A soil which is dark in color may absorb 80 percent of incoming solar radiation, while a light colored sand may only absorb 30 percent.

Water from the soil is vital to plant growth and often limits the range of various plant populations. The rate at which water will infiltrate the soil is determined by soil texture. Coarse soils admit most of the rain they receive while finer soils may lose much of it through runoff which results in erosion. Water that does enter fine grained soils is held longer and is much less mobile than in coarser soils.

Water exists in the soil in four forms:

1) Gravitational water occupies large soil pores and is readily available to plant. It drains away by gravity. Generally this draining away, with replacement by air, takes two or three days.

2) Capillary water is retained by surface forces as films around soil particles. When this water is at its peak amount, just after gravitational water has drained away, the soil is said to be at field capacity. Most of this water is available to plants, but as it is depleted, a point is reached where surface forces become so strong that plant roots can no longer absorb it.

3) Hygroscopic water is a very thin film of water which adheres to particles by surface forces. Unavailable to plants, it moves within the soil only in vapor form.

4) Vapor is the final type of soil water. It is found in the soil atmosphere and moves along gradients (Oosting, 1956).

The forces responsible for movement of water within the soil are gravity, hydrostatic pressure, capillary action, and chemical gradients.

Soil aeration is essential since roots must have oxygen for growth. The amount of air (by volume) in well-aerated soils ranges from 60 to 70 percent. This lessens as water enters the soil. In coarse soils or well-aggregated heavy soils, large pore spaces facilitate gas movement. In such soils carbon dioxide, produced by respiration of organisms within the soil, readily diffuses out, and the oxygen consumed is replenished. In poorly aggregated fine soils, toxicity due to carbon dioxide accumulation and oxygen deficiency may limit plant growth. A disadvantage of strongly aerated sandy soils is that humus content remains low due to rapid oxidation. Trees grown in very poorly aerated soils have been found to be more susceptible to root diseases than those under more aerated conditions (Daubenmire, 1974).

6.2.2.2.2 Chemical - Chemical aspects of soil that are of significance to plants include cation exchange capacity, pH, nutrition, toxicity (under certain conditions), and salinity. Imbalances of these factors often cause difficulties in establishing plant covers over sources that may emit fugitive dust.

The mineral component of the soil is composed primarily of silica, aluminum, and iron oxides. The small amounts of calcium, potassium, and magnesium which are combined in this soil fraction are not readily available to plants. The utility of this fraction lies in its ability to absorb and release nutrients. Colloidal clay particles hold nutrient minerals by the process of cation exchange. The total exchangeable cations absorbed within a soil is termed its cation exchange capacity (CEC). CEC is a measure of the soil's ability to hold nutrients.

CEC is usually high in fertile soils. Fertilizer applied to soils with coarse textures are readily leached our due to their low CEC. Soils high in colloids and/or organic matter usually display high CEC's when compared to sandy types. Calcium, magnesium, and potassium are mainly supplied through cation exchange (Beard, 1973).

Calcium is the dominant exchangeable cation in nearly all soils. It imparts chemical and physical stability to the clay-humus complex. This aids in aggregation of these fine colloidal particles, making a more desirable structure. Without calcium to produce a granular structure within clay soils, such soils would be very unfavorable to many forms of life.

While calcium ions promote soil stabilization, free hydrogen ions, derived from ionization of acids, stimulate chemical changes. Hydrogen ions are the active agents in acidic chemical action. In soil, they are derived from carbonic acid, organic acids from humus, and from acids that are products of chemical change. Their concentration is expressed as pH*. The soil pH affects nutrient availability, solubility of toxic elements, plant root development, and microbial activity. The relationship of pH and plant nutrient availability are illustrated in Figure 12 of Section 4. Under very acidic conditions, iron and aluminum become more soluble and once in solution form complexes with phosphate ions, thus tying them up. This limits the phosphorus available to plants.

In general, nutrients are most available to plants around a soil pH of 6.5. When pHs are near neutral, releases of nitrogen from organic matter is most rapid. Neutral pH favors the activity of beneficial soil microorganisms that are responsible for essential element transformation, organic matter decomposition, and nitrogen fixation. Soils of neutral pH tend to have better structure, improved moisture, and air relationships result.

Liming is used to correct excess soil acidity. Liming neutralizes acids, corrects calcium deficiency, and precipitates soluble metals (e.g., aluminum, manganese, and iron) that can reach toxic levels. Compounds used in liming contain calcium or magnesium or both. Carbonates are commonly used, but hydroxides and oxides are also used (Pearson and Adams, 1967).

The soil solution is the water in the soil with its dissolved solids, liquids, and gases. Of the 16 essential plant nutrients--carbon, hydrogen, oxygen, phosphorus, potassium, nitrogen, sulfur, calcium, iron, manganese, boron, magnesium, zinc, molybdenum, and chlorine--all but carbon, hydrogen, and oxygen are derived exclusively from the soil solution. It is thought that virtually all substances absorbed by plant roots must be in aqueous solution. Fertility is a balance of those solutes that are plant nutrients. In nature, these nutrients, with the exception of nitrogen, are derived from parent material. Rocks from which soils form are, therefore, significant. Igneous rocks of the acidic series (e.g., granite, granodiorite, rhyolite, gneiss, and schist) generally produce infertile soils while those of the basic series (e.g., basalt, andesite, gabbro, and diabase) usually yield soils with adequate amounts of plant nutrients. Sedimentary rocks such as limestone usually form fertile soils, and sandstone derived soils have a fertility level that varies with the clay content of the rock (Daubenmire, 1974). Humus developed in the soil becomes a nutrient source passed from one generation of plants to the next.

Nutrients become of concern when they are deficient. The most commonly limiting nutrients are nitrogen, phosphorus, and potassium.

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*The pH is the negative logarithm (base 10) of the hydrogen ion concentration. A pH of 7 indicates neutrality--at this pH the concentration of hydrogen ions equals the concentration of hydroxyl ions.

Hence, these are the principal components of fertilizers. Calcium may become deficient, especially in humid regions where it is lost by percolation. Additions of crushed limestone correct this deficiency.

When raw parent material first becomes available for plant colonization, it contains practically no nitrogen, phosphorus, or sulfur which are in forms usable by plants. These elements ordinarily become available through the mineralization of humus. Yet plants colonize such materials, and after a while these nutrients appear and begin to accumulate. Pioneer plants of such habitats have a low demand for these nutrients, and can absorb and accumulate very minute amounts from rainwater or from the products of weathering rock. For example, there is a liverwort which colonizes freshly deposited volcanic ash in Alaska; it thrives on a medium as low in nitrogen as it is possible to synthesize. Certain species may be able to invade relatively infertile substrata because their roots vigorously excrete carbon dioxide which can extract materials that are otherwise hard to solubilize. The process of plant succession of some soils may be governed by the rate of fertility increases (Daubenmire, 1974).

Nutrient deficiency is a common problem on mineral wastes (Cornwell and Stone, 1968; Cook, et al., 1974). Proper use of fertilizer and lime, in accordance with soil tests, may be used to correct deficiencies. It has been said that a bag of fertilizer is worth more than a bag of cement in controlling erosion. This indeed appears to be true in studies that have been conducted (Section 7).

Kirkland (1974) found that amending the spoils of an open-pit iron-titanium mine enhanced the growth of both herbaceous and woody plants. A 5-10-5 pelletized fertilizer was applied at a rate of 45 g/m^2 (400 pounds per acre). Even though soil temperature, soil moisture retention, and humus content were poor, nutrient levels were the limiting factor and were the easiest to remedy. Rates of ecological succession are stimulated by fertilizer addition.

One form of addition is the placement of a fertilizer tablet in the ground near the seedling at time of planting. One commercially available form of this fertilizer is Agriform tablets (Sierra Chemical Co.). These tables have been used in reclamation tests of Copperhill, Tennessee soil and show promise for such work (Berry, 1975). This form of fertilizer application allows nutrients to be placed near roots where they will be efficiently absorbed by the plant; thus much less fertilizer is required per acre than for less focused methods of fertilizing. Since the fertilizer is in a mass it is not as easily leached or carried away in runoff water. This mass form means that it will be made available over a long period of time.

Nutrient relations on strip mined spoils and other barren areas can be improved through the addition of organic matter which has a high cation exchange capacity. This enhances nutrient and water holding capacity. Additions of small amounts of dried activated sewage sludge to the closing hole when planting seedlings has shown promise in the establishment of trees on barren soils (Berry, 1975).

Lowry (1960) found that additions of organic additives to the root zones of conifers enhanced their survival on sandy, acid coal mine spoils. Using proper species and organic matter additions, pines can be established on sandy spoils with pH as low as 3.2. Under such harsh conditions more trees per unit area should be planted to insure a closed stand.

If enough plant nutrients are not present, deficiencies result which show up as distinct symptoms on plants, or plants simply do not grow. However, if certain plant nutrients (e.g., aluminum and manganese) are present in excessive quantities, toxicity can result.

Toxicity can occur at very low pH when metals may become so soluble that they reach toxic levels. This is one of the main adverse effects of high soil acidity.

Metal toxicity to plants has been found to be one of the main difficulties in vegetating mining and smelting wastes.

In a detailed treatment of heavy metal tolerance in plants, Antonovices et al., (1971) have discussed the establishment of vegetation on waste materials contaminated with heavy metals. Mineral tailings may be as high as one percent in a given metal and other metals may also be present. Weathering may continue to solubilize these metals for centuries. Due to the effects of toxicity, combined with lack of nutrients and poor texture, these wastes heaps remain almost barren. Covering such piles with normal soils is one technique that enables them to be planted.

but this is quite expensive. Researchers have sought to find less expensive methods of amelioration. Additives of organic wastes such as sewage sludge have shown some promise. However, with decay of the organic matter the toxic condition would return. The method of using metal-tolerant plant populations has been explored with success in England. (Goodman et al., 1973).

Berg and Vogel (1973) reported that the toxicity of acid coal mine spoils to plants is caused mainly by manganese and other metals, probably aluminum. The toxicity of manganese was seen as marginal chlorisis on legume leaves in both greenhouse and field tests. Manganese toxicity could be predicted from spoil pH, but not from measures of water-soluble manganese. Aluminum toxicity was expressed as stubby roots which lacked lateral roots. Mulching with hardwood chips raised the extremely acid pH and reduced soluble salts and water-soluble aluminum in the top 30 cm of the spoil.

Peterson and Nielson (1973) studied tailings from 15 operations. Wastes from copper, lead, zinc, and uranium mills displayed one or more adverse properties. These were poor physical characteristics, nutrient deficiencies, extremes of pH, salinity, and metal toxicity. Oxidation of sulfides (e.g., iron pyrites) was found to aggravate metal toxicity by decreasing the pH. Toxicity symptoms of particular metals were difficult to identify since metals did not occur singly. The major problem was pH. On sites where heavy metals occur, artificial leaching or precipitation along with pH control was suggested.

Goodman et al. (1973) have pointed out that grasses produced on sites contaminated with heavy metals cannot be fed to livestock due to toxic levels of these metals which are accumulated. These authors provide a discussion of ecological factors that affect plant growth on mining and smelter dumps.

Repp (1973) has investigated the chemical resistance of plants on a cellular basis. When harsh sites are to be revegetated, cell physiological resistance tests may be used to screen for suitable plant species. These tests employ tissue sections which are stressed in various ways after which cell survival is assessed. According to Repp, the effect of heavy metals seems mainly to depend on the capacity of a given metal to coagulate protein.

Besides their inherent toxicity, metals may also be harmful to plants by precipitating nutrient ions. Trace metals may also enter into reactions which result in the volatilization of the very important nutrient, nitrogen (Wullstein, 1967).

Non-metals may also bio-accumulate in certain plants grown on sulfide ore wastes. For example, animal toxicity has been observed in animals, which have fed on plants containing high levels of selenium (selenosis).

The salt content of soils sometimes reaches levels that inhibit plant growth. The osmotic potential outside roots may become so high that they are unable to absorb water. Regions that are poorly drained and that have evaporative rates suffer from high salt levels (Arnett and Braungart, 1970). Salinity is a deterrent to plant growth on tailing piles. An inverse relationship between total soluble salts and plant growth on acid mine spoils has been demonstrated (Lorio, 1962).

6.2.2.2.3 Biological -- The soil has both a flora and a fauna. The flora consists not only of the underground parts of higher plants, but also of algae, fungi, and bacteria. The fauna is made of various protozoans and different kinds of worms, insects, and other invertebrates. Small mammals such as moles, mice, and voles are also included. The abundance of microorganisms is indicated by the number found in a fertile agricultural soil (Willis, 1973):

Organism	Number per gram of soil
Bacteria	350,000,000
Actinomycetes	700,000
Fungi	400,000
Algae	50,000
Protozoa	30,000

Many of these organisms consume organic matter and thus are important in nutrient cycles. Important cycles include carbon, phosphorus, and nitrogen.

Lack of normal microbial populations has been cited as one of the adverse characteristics of mineral wastes. Wilson has reported studies of the microbiology of strip mine spoils (Wilson, 1965). His investigation showed that bacteria, fungi, and actinomycetes would increase in number as vegetation became established. Vegetation was found to exert a greater effect on spoil microorganisms than did pH. Fewer bacteria were seen in the rhizosphere (i.e., soil region around roots) than in the rhizoplane (i.e., root surfaces and adhering soil particles). Fungi of the same species were seen in both vegetated and barren areas. Amendment of the spoil with organic matter influenced both numbers and types of organisms. Microbial by-products contribute to soil aggregation. Poly-saccharides, produced by bacteria, are one such material. Bacteria which are good producers of these were lacking from nonvegetated spoils. Good producers were associated with certain plants. Microorganisms such as ammonifiers, desitrifiers, nitrifiers, and cellulose decomposers were more abundant in vegetated than nonvegetated spoil. Except for nitrifier, these organisms are heterotrophic (require organic matter for energy).

James (1966) reported that gold mine dumps in South Africa contain no organic matter and no microflora other than bacteria that oxidize iron and sulfur.

In his study of plant colonization of coal mine waste, Schramm (1966) found that waste devoid of higher plants lacked fungus. But wherever tree species that were potentially ectomicorrhizal were established, basidiomycetes could be found. Few fungal species were encountered within the anthracite spoils.

Marx (1975) has pointed out that manipulation of mycorrhizal fungi on roots of plants can have great potential for revegetaion of devasted areas. Mycorrhiza are special compound structures that consist of plant roots and fungal mycelia. The fungus invades the roots of plants and either forms a mantle around the root or invades the cortex of the root. In any case, the fungus aids the plant in absorption of both water and minerals while obtaining nourishment from the plant. The occurrence of mycorrhizal associations are so common that the nonmycorrhizal plant is the exception rather than rule. Most plants form these associations and some plants, pines in particular, cannot develop normally or survive without the presence of these fungi. Mycorrhiza appear to increase the drought tolerance of trees, as well as their tolerance to high soil temperature, soil toxins, and extremes of soil pH caused by high levels of sulfur and aluminum.

Two factors which affect mycorrhizal development are light intensity and soil fertility. High light intensity and moderate to poor soil fertility enhances the growth of beneficial fungi which form them. It can readily be seen that if mycorrhizal fungi are not present in a certain area, vegetation would be aided if they could be introduced. Introduction can be accomplished readily in either of two ways. Prepotted nursery stock innoculated with the fungi can be used in the revegetation effort; this is especially helpful if young trees or shrubs are being planted. An alternate method is to spread the area to be planted with a light covering of forest topsoil (Marx, 1975).

A second type of plant root relationship is that involved in the association between certain types of plants, primarily legumes, and the nitrogen-fixing bacteria. These bacteria invade the roots of legumes causing nodules to form. Such bacteria can take nitrogen from the air, which is not available for use by higher plants, and convert it to a usable nitrate form. By this action, as legumes die off, the bacteria release a valuable nitrogen source for other plants, making legumes particularly useful in many revegetation plans.

6.2.3 Climatic

Climatic factors affect many plant processes and are responsible for the range of plant populations (Searle, 1973). Each factor makes a vital contribution to sustaining plant life.

Climates in areas of the United States where fugitive dusts are likely to present a significant problem, will generally be harsh and unfavorable for vegetation. Daytime temperatures will probably be high, rainfall low, and winds strong and dry.

In the following sections major climatic factors--light, precipitation, wind, and temperature--will be discussed briefly.

6.2.3.1 Light -- The main importance of light, of course, is that it drives the photosynthetic cycles of green plants. Sunlight is very unlikely to be limiting except where dense vegetation produces a heavy shade. Actually, many plants are saturated with respect to light at around 20 percent of full sunlight (full sunlight taken to be 10,000 footcandles, 108 k lumens/m^2). The quantity as well as quality of light is important to photosynthesis. The wavelengths between 400 and 700 nm are particularly important since this is the region of the spectrum which drives photosynthesis.

Competition for light does become critical in dense stands of vegetation. Germination of some seeds has certain light requirements. Certain seedlings (e.g., longleaf pine (Pinus palustris)) cannot survive under shady conditions.

Photoperiod (i.e., day length) often influences plant growth and reproduction. This phenomenon is largely responsible for many seasonal changes observed in various plant species.

Light becomes a problem where plants grown under nursery conditions, protected from strong light, are planted in the field. Because they are not conditioned (i.e., hardened), a large percentage of them may not survive.

In general, light will not be a problem in revegetation of barren areas except perhaps indirectly as the source of high surface temperatures.

6.2.3.2 Precipitation -- In all probability, water is the single most important factor affecting plant growth. In areas where rainfall is high, fugitive dust is less likely to be a problem because in these areas vegetation is usually plentiful. In addition, wetted surfaces are not easily eroded by wind. Water shortage is the number one limiting factor in plant production in many areas of the United States today; consequently, special techniques for dry land farming have developed (e.g., mulching, strip cropping, and summer fallow).

The necessity of water for plant growth cannot be overstressed. The plant body itself is usually 60 to 90 percent water. Not only is water essential for physiological processes, but it also mobilizes soil nutrients, making them available for use by the plant. All land plants constantly lose water through their leaves as vapor in the process of transpiration. Great quantities are lost this way. A single corn plant may transpire more than 2 liters of water per day.

The seasonal distribution of precipitation is quite important since growing vegetation must have some minimum level of moisture available constantly. This distribution has to be taken into account in planning irrigation programs.

Mulches may be used to help conserve water in the soil. Besides traditional forms of mulches, there exist the possibility of using various polymeric sprays on the soil surface to help retain water.

Direct conservation of water within the plant itself may be brought about by the use of antitranspirants. Antitranspirants are chemical films of various types that are applied directly to plants as sprays (Gale and Hogan, 1966). Their use might prove useful for establishing seedlings in harsh environments.

6.2.3.3 Temperature -- The major impact of temperature on living organisms lies in the fact that raising the temperature increases the speed of biochemical reactions. For every organism there is a definite temperature range in which it can live. But for plants as a whole, the range is wide--from 80°F (27°C) for subartic conifer forests to 140°F (60°C) for some desert species.

Temperatures on the earth are seldom too hot or too cold for plant life, although temperature periodicity is very important. As seasonal temperatures decrease, plants "harden" and become dormant. This affords them protection in winter.

Another important aspect of temperature periodicity is the diurnal cycle where daytime temperatures are higher than night. If night temperatures become higher more products of photosynthesis, which are produced only in light, will be consumed by respiration during dark hours. This has an adverse affect on plant vigor since food supplies are depleted.

Surface temperatures are a problem on barren areas, especially those which are dark in color. Schramm (1966) reported that high surface temperatures were a major deterrent in the natural establishment of plants on anthracite wastes. These black wastes reached temperatures as high as 75°C in flat areas. Emergent seedlings were heat girdled at the stem bases or killed underground before breaking the surface. The best area so far as temperature was concerned were shaded microhabitats on steep northerly slopes. Nonlethal temperatures also damaged young stems, induced dormancy in certain pine seeds, and upset the normal geotrophic behavior of roots. Superior heat resistance was noted for two pines, *Pinus virginiana* and *Pinus rigida*.

6.2.3.4 Wind -- Direction, intensity, and duration are the variables of concern in considering wind effects on plants. The movement of air on a microscale basis serves to deliver carbon dioxide to leaves, where it is consumed in the process of photosynthesis. In still air, a 1 to 2 mm boundary layer exists which impedes diffusion. Gas exchange is favored by vigorous air movement which thins this boundary layer.

Wind serves to cool leaves, but at very low temperatures this cooling may become detrimental. Wind action may also desiccate leaves, and very dry winds can cause severe damage.

Wind is the main factor to be controlled in preventing soil particles from becoming airborne. When winds are strong, the particles carried may cause substantial abrasive damage to plants. When plantings are to be made on potentially dusty sites, provision will have to be made to control this abrasion until plants are well established.

6.2.4 Atmospheric

The atmosphere supplies the carbon dioxide which is the main raw material for photosynthesis in plants. It also serves as a sink for oxygen released by plants.

In this century, atmospheric pollution has become acute in some areas of the world. The most important pollutants are sulfur dioxide, ozone, nitrogen oxides, hydrocabons (indirectly), carbon monoxide, and particulates. The effects of these materials on plants have been considered by many workers (Jacobson and Hill, 1970).

Because smelting and mining wastes are often located in industrial areas, pollutants in the air may be harmful to plants that are used as covers for these materials. In fact, sulfur dioxide in the air is currently the main problem in establishing vegetation in the Copperhill, Tennessee area rather than any soil deficiency or climatic problem (Berry, 1975).

6.2.5 Biotic

The biotic environment includes all of the living things in the environment. Organisms in a given locality which interact comprise a community. There is continuous competition within a given species (intraspecific) and among different species (interspecific).

There are three major types of organismic interaction; these are commensalism, mutualism, and parasitism. In commensalism, plants which associate neither harm nor benefit each other. Among plants this type of relationship is demonstrated by epiphytes which grow on trees. Mutualism between plants results when both members of an association derive benefit from each other. Nitrogen fixing relationships between legumes and bacteria are of this type. Both commensalism and mutualism are forms of symbiosis--intimate associations where neither organism is harmed. Parasitism results when one organism, the parasite, depends on another, the host, for all or part of its nutrition. The host is weakened by this relationship; many plant diseases fall into this category. Misteltoe, for example, is parasitic on hardwoods.

The possibility of plant diseases should be considered when harsh sites are to be planted. Under such circumstances, plants weakened by adverse conditions can be more susceptible to diseases.

Plants compete with each other for root space and exposure to light. The more crowded the plants, the greater will be the reduction in size and the number of seeds produced. There are some benefits from crowding, however. If a group of plants occupies all the available space, they provide a unified front against the invasion of other species. Dioecious plants (i.e., separate sexes) must be close enough together so that fertilization can readily occur.

Competition among different species occurs everywhere. Any disease or other factor that weakens one plant will give the advantage to another plant. Some plants produce fast growing runners that are effective in quickly invading new territory.

Animals influence plant populations through consumption and by distributing plant propagules. Overgrazing by cattle has been cited as a serious problem in revegetation efforts in some areas.

7.0 CASE HISTORIES AND RECOMMENDED METHODS FOR TERRAIN STABILIZATION BY VEGETATIVE COVER

The term "vegetative cover" spans a spectrum of microvegetative species such as algae, lichen and mosses through grasses, legumes, vines, shrubs and trees. Natural vegetative succession in inhospitable soils are discussed in Section 6.1; the present section reports on specific efforts to establish vegetative cover on common types of mine and mineral waste heaps, and summarizes recommendations based on these efforts.

The section is organized by waste types. Section 7.1 covers coal mine refuse and spoils, Section 7.2 reviews mineral ore tailings, Section 7.3 discusses spent oil shale deposits, and Section 7.4 deals with sand and gravel pit revegetation. A catalog of plant species used in revegetation efforts is given in Appendix B. The entries in this catalog include the common and scientific names of the plants, general information about recommended growing conditions, and summaries of attempts to use the species in specific revegetation programs.

7.1 COAL MINE REFUSE AND SPOILS

Mined coal is invariably accompanied by a large quantity of waste material, which consists principally of varying amounts of slate, carbonaceous and pyritic shale, clay and sandstone. The wastes and unrecoverable coal obtained in underground mining are separated from the recoverable coal in a preparation plant; fine wastes (primarily coal, ash and pyrites) are mixed with water and pumped to slurry ponds, and coarse wastes (coal, shale, clay and sandstone) are dumped to fill valleys or to form refuse banks (also called refuse piles, gob piles or culm banks). The refuse banks are aesthetic blights, subject to spontaneous combustion which can last for decades once begun, and represent serious sources of water pollution (through acid drainage and siltation into streams and lakes) and air pollution (through fugitive dust emission and release of noxious combustion products).

Additional environmental problems are created when coal is surface-mined. The composition of the material covering a coal seam (the overburden) varies considerably with position relative to the surface. When the excavated trenches or pits are refilled, the resulting surface may be incapable of supporting natural revegetation.

Strip mining is carried out in several ways, of which the principal two are area stripping, in which parallel trenches are dug in relatively flat or rolling terrain, and contour stripping, in which cuts are made around a hillside.

In area stripping, the overburden removed from each cut is used to fill in the previous cut. A worked-out stripped area consequently consists of a series of ridges and troughs (the spoil banks) with a deep final cut where the last trench was excavated. The final cut is bounded by a long slope on the side of the spoil banks (the outslope) and a steep wall on the opposite side (the highwall). The distance between spoil bank ridges varies from 11 to 21 m (35 to 70 feet), and the ridges generally vary in height from 3 to 6 m (10 to 20 feet). The highwall may vary in height from one meter (3 ft) to as much as 30 m (100 feet).

A hill which has been countour-stripped has several topographic features in common with an area-stripped region. A series of terraces go up the surface of the hill; each terrace consists of a highwall on the uphill side, a flat bench with a relatively slight grade, and a long and frequently steep outslope covered with the excavated overburden.

An important part of modern strip mining operations is planning the excavation and spoil redistribution so that the overburden materials which are least supportive of plant growth--particularly stony and pyritic shales--are buried deep in the spoils when the mining has been completed. Backfilling and grading of spoil banks and highwalls to restore the land to its original contour and covering with one or more feet of topsoil prior to vegetating may be performed, either voluntarily or under mandate of law.

Revegetation of coal mine spoils has been practiced for many years in most coal-producing areas of the world, and the literature abounds with planting recommendations and comparative species evaluations.

Despite the volume of published information, however, the subject has not nearly reached the point where the correct species to plant on a given spoil can be specified with certainty, and research on the performance of existing species and the development of new ones is currently under way at agricultural and forestry experiment stations throughout the country.

Several general references discuss revegetation of coal-mine spoil areas. The document Surface Mining and Reclamation in Kentucky (1972) provides a good survey of both mining and spoil reclamation techniques. Other references which discuss the rehabilitation of surface mine spoils are the Revegetation Manual (1966), published by the USDA Forest Service in Berea, Kentucky; A Guide for Revegetating Bituminous Strip Mine Spoils in Pennsylvania (1965, rev. 1971) published by the Research Committee on Coal Mine Spoil Revegetation in Pennsylvania and obtainable from the US Soil Conservation Service in Harrisburg, Pa.; and papers by Carter et al. (1973, 1974), Limstrom (1960) and Cook et al.(1974). Discussions of techniques for stabilizing refuse banks and slurry ponds are presented by Coalgate et al. (1973) and Kosowski (1973). Cost analyses and case studies of both deep mine and surface mine-spoil reclamation are contained in Bureau of Mines document PB-226 725 (1973) entitled "Methods and Costs of Coal Refuse Disposal and Reclamation", obtainable from the National Technical Information Service (NTIS).

The most comprehensive summary of references on mine spoil reclamation is contained in Surface Mining and Mined Land Reclamation: A Selected Bibliography, published in October 1974 by the Old West Regional Commission, 1730 K Street, N.W., Washington, D.C. 20006. This document lists 1337 references, which include earlier bibliographies, citations of legal opinions, environmental impact and economic studies, and studies of spoil properties, planting techniques, and species selection, with a special section devoted to revegetation of arid and semi-arid lands.

The pages that follow review the material in the general references cited above and in specific case studies of mine spoil reclamation efforts. Section 7.1.2 summarizes recommended procedures for mine spoil reclamation programs; topics discussed include grading and soil cover; species selection for revegetation of acidic spoils and steep slopes; various factors involved in the selection of grasses, legumes, shrubs and trees; soil treatment procedures (liming and fertilizing); and planting and mulching techniques. Section 7.1.3 dicusses the revegetation of refuse banks and slurry ponds, both with and without soil covers, and Section 7.1.4 discusses surface mine spoil revegetation efforts in the East, Midwest and West.

At the conclusion of Section 7.1 is a table of species which have been used for coal mine spoil reclamation, and separate tables of acid-tolerant species. Each of the species listed in these tables and in Sections 7.1.2 through 7.1.4 have entries in the plant catalog of Appendix B, in which are given the scientific names of the plants, general recommendations for planting, and results of mine-spoil revegetation efforts in which the plants were used.

7.1.2 Elements of A Mine-spoil Reclamation Program

A good survey of the steps involved in the reclamation of a coal mine spoil is contained in Surface Mining and Reclamation in Kentucky, (1972), published by the Division of Reclamation of the Kentucky Department of Natural Resources. This document presents several hypothetical case studies, and provides the reader with a highly readable chronological picture of the problems faced by the mine operator at each stage of his operation, along with recommended solutions of these problems. The Guide for Revegetating Bituminous Strip-Mine Spoils in Pennsylvania (1965, rev. 1971) and the Revegetation Manual (1966) are also excellent sources of general information and recommendations.

A point made in all of the various published guides for surface mine spoil reclamation is the need for soil testing and planning before mining begins. The soil overlying the coal to be mined should be subjected to a complete analysis, with core-drilled samples being taken at a series of depths from the surface to the coal seam. The overburden from adjacent mining operations should also be examined, both to determine its composition and to see what vegetation is growing on it. A long range land use plan should then be developed, since the reclamation procedures needed to establish woodland, agriculture, recreation or wildlife areas on the abandoned spoils may differ considerably. The ultimate use of the land is partially governed by economic considerations, but may be largely dictated by the topography of the mine region and the results of the soil tests; anything may be grown on neutral, nutrient-rich spoils, but stony or highly acidic nutrient-deficient spoils may be capable of supporting species suitable only for wildlife areas.

A number of potential obstacles to revegetation may be revealed by soil tests, including overburden strata with poor chemical properties (e.g., high acidity, alkalinity, or salinity, or high levels of potentially toxic elements) or poor physical properties (e.g., low soil content or excessive proportions of sand or clay). A discussion of these and other soil properties and their effects on the establishment and growth of vegetation has been given in Section 6. If problem spoils are predicted by preliminary soil tests, plans should be made to backfill and grade the spoils in such a way that the worst of the overburden is buried; this may entail removing and preserving separately the overburden nearest the surface and using this material as a final cover.

After mining operations have been completed, the spoils should be subjected to another series of tests. The Guide for Revegetating Bituminous Strip-mine Spoils in Pennsylvania (1965) suggests preparing a spoil classification map, which shows the slope, pH, stoniness and particular problems associated with each region of the mined area. A detailed revegetation plan should then be formulated using this map as a guide: among the decisions to be made are 1) whether and how much to grade or reshape the spoils; 2) whether to add a soil cover or to attempt to revegetate the spoils directly; 3) which species to plant and how to plant them; 4) what type and how much lime, fertilizer and mulch to add.

During each stage of the planning, mining and reclamation operations, an agronomist familiar with soils and natural vegetation in the area to be reclaimed should be consulted. Staff scientists at university, state and federal agricultural and forestry experiment stations are always extremely helpful in this regard (see Appendix C).

The sections that follow contain general guidelines and suggestions for mine spoil reclamation procedures, based on published studies of successful and unsuccessful revegetation efforts.

7.1.2.1 Grading -- Spoils and refuse banks should be graded to a slope of less than 25 percent for agricultural uses, and to less than roughly 35 percent for recreation and wildlife uses. A minimum grade of 1-2 percent should be provided to prevent impounding of water. Diversion furrows or ditches should be provided to allow drainage and to control erosion (Guide to Revegetating.., 1965).

Grading may have a positive or negative effect on plant growth, depending primarily on the soil texture. Soils with high clay contents tend to become overcompacted when graded, thereby reducing the possible rate of water infiltration. Species planted on such soils may consequently have a lower probability of survival, and if they survive they may grow at a low rate relative to the same species planted on ungraded spoils. Many case studies of plantings on spoils in the Midwest, which are characterized by high clay and limestone contents, show evidence of this negative grading effect (Chapman, 1967; Clark, 1954; Geyer and Rogers, 1972; Merz and Finn, 1951). Chapman (1967) recommends avoiding grading whenever possible on soils with clay contents in excess of 15 percent. On the other hand, survival and growth on coarse spoils of the type more common in Pennsylvania may be helped by grading, a phenomenon cited by Czapowskyj (1970).

Possible changes in the chemical makeup of the surface material due to grading should be taken into account when selecting species to plant. Spoils tend to be nonuniform in acidity, for example, and grading may take concentrated highly-acidic regions and either bury them (which is desirable) or spread them out, which may be good or bad, depending on the size of the acid region and the species to be planted.

7.1.2.2 Soil Cover -- The spoil revegetation technique which is most likely to succeed is to apply a soil cover prior to planting. The problem with this approach is the cost of transporting, spreading and compacting the soil cover, a cost which normally far exceeds the cost of planting. In revegetation projects cited in Methods and Costs of Coal Refuse Reclamation and Reclamation (1973), planting costs ranged from 1.2¢ to \$0.11 per m^2 (\$48 to \$455 per acre) while soil cover costs ranged from \$0.16 to \$2.69 per m^2 (\$665 to \$10,900 per acre).

It is clearly desirable to minimize or eliminate the necessity for soil cover, and to find species which will grow directly on spoil material. Direct revegetations of strip mine spoil banks are numerous, and several instances of successful slurry pond revegetations are recorded (See Section 7.1.3); there have been no particularly successful revegetations directly on coarse refuse, however, so that given the present state-of-the-art, direct revegetation of a bare refuse bank should probably not be attempted on anything but an experimental basis.

When a soil cover is not required by state regulations, the need for one depends on the spoil analysis--particularly the pH, the concentrations of potential toxins like aluminum and manganese, and the soil content. A spoil with a pH less than about 3.5 which also has a high sulfur content should always be covered, since even if lime is added to raise the pH, the sulfur eventually oxidizes to form metal sulfates and sulfuric acid and the pH drops again. Spoils containing excessive quantities of trace metals and soluble salts may be leached (irrigated and drained to remove the objectional material), but this is generally an inefficient process and covering may be preferable.

A minimum of 20 percent of soil-sized particles (mean diameters less than 2 mm) is considered necessary to support plant growth (*Tree Planting in the Allegheny Section*, 1961). The problem of excessive stoniness may be partially alleviated by *weathering* of the refuse-- a combination of physical disintegration and chemical decomposition over a period of time. If a stony spoil contains quickly decomposing shales, it should be given three years to weather before planting is begun; if it is primarily sandstone and other slowly weathering materials, and contains less than the minimum proportion of soil-sized particles, a cover is necessary (Coalgate, 1973).

A one-foot soil cover has been recommended for plateaus by several authors (Brundage, 1974; Kosowski, 1973; *Methods and Costs of Coal Refuse Disposal and Reclamation*, 1973), and a deeper cover is suggested for slopes. The choice of a cover material (undisturbed soil, strip mine overburden, and digested sewage sludge being three possible alternatives) is discussed in detail in Section 7.1.3.

7.1.2.3 Species Selection -- The choice of species to plant is largely dictated by local climatic conditions, desired land use (cropland, livestock forage, timber production, or recreation and wildlife preservation), and the physical and chemical makeup of the spoil or soil cover to be revegetated.

General species recommendations for different types of soils are given by Searle (1973), and species recommended specifically for mined land revegetation are summarized in Sections 5.1.3 and 5.1.4 and in Table 17. General considerations which go into making the choice are summarized below.

7.1.2.3.1 Planting on acid spoils -- Few plants can grow satisfactorily on soils with pH less than 5, so that it is normally advisable to use an alkaline material to bring the pH of acidic spoils at least to this level and preferably to a value in the range 6 to 8. The most common neutralizing material is agricultural limestone; other materials which have been used on an experimental basis include power plant fly ash (Capp and Gillmore, 1973), municipal sewage effluent (Sopper et al., 1975), and mined phosphate rock (Armiger et al., 1975; Bennett, 1971).

The normal neutralization procedures is to mix the lime into the top six inches of the spoil; on particularly acidic spoils with high sulfur concentrations, the lime should be mixed to a depth of 12 inches (Revegetation Manual, 1966). It is preferable to allow six months for the lime to react with the acidic materials in the spoil before seeding is attempted, assuming this requirement does not conflict with state regulations (Ibid.).

Even after the soil has been neutralized, oxidation of sulfides to acid sulfates may eventually lower the pH again, so that it is usually best to choose species known to be acid-tolerant for revegetating pyritic spoils.

Tables 18, 19 and 20 list grasses, legumes, shrubs, and trees which are known to be acid-tolerant. (Searle, (1973) may also be consulted in this regard). Additional points concerning survival and growth in acidic media are given below.

Most of the species known to tolerate highly acidic soils (pH less than 4) are trees and shrubs; of the trees, most are conifers, with the exceptions of gray and white birch, red oak, black locust and European alder.

The most widely recommended tree for acid sites at this time is European black alder. Like black locust, the alder fixes atmospheric nitrogen and serves as a good nurse crop for other species; it is somewhat less vigorous than locust, but it lives longer, has a much better form, and has a potential for timber production which locust does not. It has survived at a pH as low as 3.5 (Ruffner, 1966). It is subject to damage by drought, however, and should not constitute more than one-third of any tree mixture (Guide for Revegetating..., 1965).

Black locust has usually had the best survival and short-term growth record of any species tested in a given location (Brown and Tryon, 1960; Clark, 1954); however, its poor form and susceptibility to borer damage have led to its general abandonment for reclamation projects except as a nurse crop for other species or on steep slopes or ridges where no other species can be induced to grow (Medvick, 1973). Recently, efforts have been undertaken to develop a hybrid black locust which retains the acid tolerance of this species but displays better form and resistance to borer attack. The result is the "dominant stem" black locust, which shows considerable potential for use in revegetation of acid spoils (Ruffner, 1966; Ruffner and Stevens, 1973).

Other hardwoods which tolerate pH less than 4 include aspen (Knabe, 1964), which has been observed to invade strip mine spoils in Pennsylvania and West Virginia (Medve, 1974; Mellinger et al., 1966), and gray birch, European white birch and river birch (Guide for Revegetating..., 1965; Horn and Wood, 1969; Knabe, 1964; Revegetation Manual, 1966; Wheeler, 1965). Red oak has been known to survive at pH 3.2 (29 percent after 10 years--Hart and Byrnes, 1960), but grows slowly at first. Knabe (1964) suggests black cherry as part of a mixture on acid spoils. Several authors suggest hybrid poplars for low pH soils (Davis, 1964; Eschner, 1960; Jones, 1973), but their precise capabilities are still not known and clone selection makes a great difference in performance.

A Virginia pine has been observed growing in Indiana at a pH of 3.5, and a hybrid of pitch and loblolly pine survived at a pH of 2.5 (Limstrom, 1964). Virginia pine is one of the most widely recommended conifers for acid spoils; it is considered by some to be the most acid-tolerant pine (Miles *et al.*, 1973) and has done comparatively well in survival and growth on near-toxic sites (Boyce and Neebe, 1959; Czapowskyj and McQuilken, 1966; Dale, 1963; Mellinger *et al.*, 1966; Ruffner, 1966); however, it is usually outperformed by other conifers in tests on moderately acid to neutral soils (Boyce and Neebe, 1959; Brown, 1962).

Pitch pine is acid-tolerant but has poor form and growth and is not recommended for forest plantings (Boyce and Neebe, 1969; Czapowskyj, 1970; Geyer and Rogers, 1972; Hart and Byrnes, 1960). Red pine and jack pine are also highly acid-tolerant although, like Virginia pine, they are not good choices for better soils; they require well-drained soil and are susceptible to tip moth and sawfly damage (Finn, 1958). Red pine is recommended for acid spoils in Pennsylvania (*Guide for Revegetating...*, 1965), but it is highly susceptible to tip moth damage and its use in Indiana plantings was discontinued in 1963 (Medvick, 1973). Jack pine has good initial growth but slows up considerably between 10 and 15 years after planting (Wheeler, 1965).

White pine has been used extensively, but its growth during the first three to five years is usually less than that of most other pines; it is susceptible to weevil infestation, and it is less acid-resistant than Virginia, pitch, jack, and red pines (Czapowskyj, 1970; Funk and Krause, 1964; *Guide to Revegetation*, 1965; Lowry, 1960). Its potential for long-range growth (greater than 20 years) on acid spoils as not been adequately explored.

Several acid-resistant shrubs have been cultivated. Arnot bristly locust has been found to provide effective cover for pH greater than 3.5 and is particularly recommended for erosion control on steep outer slopes of spoil banks (mcWilliams, 1971; Miles *et al.*, 1973; *Revegetation Manual*, 1966; Ruffner and Stiner, 1973). The "belmont" strain of Japanese fleeceflower grows and reproduces at a pH of 3.5 and tolerates as pH as low as 3.2 (Ruffner and Steiner, 1973). Horn and Ward (1969) found scotch broom to be the most acid-tolerant shrub they tested, followed by Japanese and bicolor lespedezas and autumn olive. Autumn olive is also recommended by Carter, *et al*. (1974), the *Guide for Revegetating* (1965), and the *Revegetation Manual* (1966). Ruffner (1965) suggests that autumn olive may tolerate a pH in the range of 3-4, and both Ruffner (1966) and Mellinger *et al*. (1966) rate it second only to black locust in its ability to provide cover on poor sites.

For pH greater than 4.5, any of the species listed in Tables 5-2, 3, and 4 may be planted.

7.1.2.3.2 Planting on slopes -- Establishment of vegetation on steep slopes is relatively difficult, since the slopes are difficult to access and are susceptible to severe, rapid erosion. Hydroseeding (mixing and spraying a slurry of water, fertilizer, seed, and a wood fiber or paper pulp mulch on the areas to be revegetated) is presently the most effective technique for slope reclamation (*Surface Mining* [illegible] *Reclamation in Kentucky*, 1972).

When trees or shrubs rather than grasses and legumes are to be established on slopes, direct planting rather than seeding is generally recommended. The few woody species which have been successfully seeded include black locust, bristly locust and shrub lespedezas (*Revegetation Manual* 1966). The most difficult type of area to revegetate is a steep slope which is highly acidic. Ruffner (1965) recommended bristly locust for this purpose, since it can be seeded, provides quick stabilization, and is acid-tolerant.

Soil and drainage characteristics vary bewtween the upper and lower slopes of spoil banks, and different species are frequently recommended for these locations. On highly acidic Pennsylvania spoils, red oak is recommended for the lower slopes, and black locust is suggested for the upper slopes (Hart and Byrnes, 1960). On Illinois spoils, conifers are recommended for ridges and upper slopes, and hardwoods are recommended for lower slopes and valleys (Boyce and Neebe, 1959). Tree survival also depends on the direction in which the slope faces, and is generally better on slopes with a northern or eastern exposure (Clark, 1954; Czapowskyj and Writer, 1970; Limstrom and Merz, 1949; May *et al*., 1971; Schramm, 1966).

7.1.2.3.3 Choosing grasses and legumes -- Most spoils are deficient in nitrogen, and the inclusion of at least 5 to 10 percent of a legume in seeding mixtures to fix atmospheric nitrogen is usually essential (Medvick, 1973; Struthers, 1960). Legumes should always be inoculated with suitable growth-inducing microorganisms prior to planting (Carter et al. 1974). Particular grasses and legumes recommended for spoils of different types are listed in Table 17.

The most widely recommended perennial grass is tall fescue, usually the Kentucky-31 variety. Several varieties of wheatgrass have been used with good results in reclamation of western spoils, and bermudagrass and bahiagrass are effective in the South. On acidic spoils (pH less than 5.5) bermudagrasses, deertongue and weeping lovegrass are preferable to fescue, which is susceptible to aluminum toxicity in acidic spoils (Vogel and Berg, 1968). Deertongue is particularly acid resistant, but it is difficult to establish (Ruffner, 1966). Annual or perennial ryegrasses are almost invariably chosen for short-lived, quick cover; millet grass is also used for this purpose in the South.

The most widely recommended legumes are alfalfa, birdsfoot trefoil, crownvetch, flat pea, and Sericea lespedeza. Alfalfa works quite well on relatively nutrient-rich soils with pH greater than 6, but tends to fail under difficult growing conditions.

Birdsfoot trefoil and crownvetch provide attractive ground covers, but may be difficult to establish. Birdsfoot trefoil, particularly the Empire variety, has reasonably good acid tolerance, and is salt and drought-resistant (Sorrell, 1974). Crownvetch is less acid-tolerant, is effective on slopes, and should be planted with a quick cover grass such as weeping lovegrass or annual ryegrass. It may take up to three years to establish a good stand by planting, and is often extremely difficult to establish by seeding, although Ruffner (1966) reports success in this regard.

Flatpea is acid-tolerant and drought-tolerant, but slow to establish, and produces seeds which are poisonous to livestock (Miles et al., 1973; Ruffner, 1966).

Sericea lespedeza has been recommended for a wide variety of soil and climatic conditions; it grows best on well-drained loose soils, and prefers a pH between 6 and 6.5 but grows in the range 4-7 (Guernsey, 1970). Kobe lespedeza may be somewhat more tolerant of acidic conditions (Berg and Vogel, 1968).

Several varieties of clover and sweetclover have been used in plantings, but with mixed success except under ideal soil conditions. Kudzu is also an effective plant for spoil reclamation, but it tends to smother everything else around it (Figure 14) and should not be used in mixed plantings or in plantings where other vegetation is already present.

7.1.2.3.4 Choosing trees and shrubs -- The selection of trees and shrubs is more geography-dependent than is the selection of grasses and legumes. Comparative species ratings and recommendations are given in Section 6.1.4, which reviews spoil revegetations in different regions of the country. The sections that follow discuss more general considerations in the selection and planting of trees.

7.1.2.3.5 Planting trees on spoils with existing herbaceous covers -- A common technique is to plant a cover of grasses and legumes to provide rapid stabilization of a spoil bank, and to overplant trees for long-range reclamation. Some caution is necessary when doing this, since some herbaceous species--particularly grasses--may hurt the growth of the trees. Tall fescue and ryegrass in particular tend to suppress tree growth, and the partial replacement of these species by weeping lovegrass and legumes in areas to be reforested is recommended (Revegetation Manual, 1966). An alternative is to plant an annual grass in the Spring, let it die, and then plant trees (Ibid.).

7.1.2.3.6 Conifers vs. hardwoods -- No unanimity exists on the relative merits of conifers and hardwoods. On acidic soils, the best species for quick stabilization and growth are nitrogen-fixing hardwoods like black locust and European alder, followed by various pines. Czapowskyj (1970) and Chapman (1967) indicate that hardwoods generally survive and grow better than conifers on Pennsylvania anthracite spoils and spoils in the central states respectively, while the Revegetation Manual (1966) makes the opposite claim for Kentucky. Boyce and Neebe (1959), in recommending species for Illinois, suggest that pines are better on acid spoils and hardwoods are preferable for calcareous areas; they also recommend planting conifers on ridges and upper slopes, and hardwoods in lower slopes and in valleys. Limstrom (1960) indicates that both hardwoods and conifers are adaptable to sands or loose loams and clays, but most pines should not be planted on compact loams and clays, the exceptions being white pine and eastern red cedar.

7.1.2.3.7 Mixed tree plantings: nurse species -- As a rule, mixtures of tree species should be planted, since most areas to be revegetated vary in composition from one point to another and the best species for one site may not be the best for another (Medvick, 1973). Limstrom (1960) recommends planting bands of five rows each or blocks of different species. The Revegetation Manual (1966) offers the same suggestion with respect to pines, sycamore, cottonwood and hybrid poplar, and suggests planting other hardwoods in mixtures; the same reference suggests 30-50 ft strips of shrubs and trees alternating with strips of grasses and legumes of the same width as an attractive scheme for wildlife preservation areas. Smith (1971) proposes alternating rows of pioneer species (black locust and European alder), pulpwood species (cottonwood, silver maple, sycamore, red gum, bigtooth aspen and autumn olive) and timber species (red oak, white oak, tulip tree, white ash and black walnut).

Much has been written about the interplanting of nitrogen--fixing trees to act as nurse species--i.e., to facilitate growth of other interplanted species. Black locust has traditionally been used for this purpose, but many plants cannot compete successfully with black locust and caution should be exercised when using this tree in mixed plantings. In particular, it has been suggested that black locust not be interplanted with conifers, sycamore or cottonwood (Limstrom, 1960), and that no more than 25 percent of black locust be included in any interplantings (Carter et al., 1974; Revegetation Manual, 1966). Species which reportedly do well interplanted with black locust include red oak, yellow poplar, sweetgum, and green and white ash (Limstrom, 1960).

European alder is frequently included instead of black locust as a nurse in plantings. It has a beneficial effect on the growth of hybrid poplars (Knabe, 1964), and on the survival and growth of ash and several pines on acid soils (Dale, 1963).

The damage done by nitrogen-fixing nurse species usually occurs when the nurses overtop the species they are supposed to be helping. An alternative is to interplant a nitrogen-fixing shrub, which functions as a nurse but remains below the growth level of the interplanted trees. Shrubs recommended for this purpose include autumn olive, bristly locust, and Natob bicolor lespedeza (Revegetation Manual, 1966); the first two are particularly suited to acid spoils.

7.1.2.4 Soil Neutralization -- When the pH of a soil is less than about 5, metals such as aluminum and manganese in the soil dissolve and become available to plants in potentially toxic quantities, and at the same time important nutrients like phosphorus and potassium precipitate out and become unavailable to the plants (McCart, 1973). Raising the soil pH above 5.5 by applying an alkaline material is usually sufficient to overcome these problems.

Agricultural limestone is the most commonly used neutralizing material. Burned lime and hydrated lime can also be used, but they are generally much more expensive (Revegetation Manual, 1966). Other materials which have been used on an experimental basis include power plant fly ash (Capp and Gilmore, 1974) and municipal sewage effluent (Sopper et al., 1975; Bennett, 1971). The first two of these materials are discussed in greater detail in Section 7.1.3. The effectiveness of a combined treatment with limestone and sewage sludge has been noted by several authors (Carter et al., 1974; Sutton and Vimmerstedt, 1973).

The amount of neutralizer to apply can be determined from a soil analyhsis. If liming is to be carried out at all, the pH of the soil to be treated should be raised to at least 6.0 for the establishment of grasses, legumes or hardwoods, and to at least 5.5 for conifers or acid-tolerant shrubs. If conifers are to be planted, the pH should not be rasised above 6 since above this pH the level of iron in the soil falls below the optimum range for conifer survival and growth (Lowry, 1960).

The normal neutralization procedure is to mix the lime into the top 6 inches of the spoil; on particularly acidic soils with high pyrite concentrations, the lime should be mixed to a depth of 12 inches (Revegetation Manual, 1966). It is preferable to allow six months for the lime to react with the acidic materials in the spoil before seeding is attempted, when this requirement does not conflict with state regulations (Ibid).

Lime can be spread in relatively flat regions by conventional techniques and a blower mounted on a lime truck has been found effective for applying lime to outslopes (Revegetation Manual, 1966). Using a tractor at the top of a ridge to drag a chain across a slope has been found to be an effective way to work the lime into the soil (Ibid.).

7.1.2.5 Fertilization -- The principal nutrients required for plant growth are nitrogen, phosphorus and potassium (See Section 6). Mine spoils are almost invariably deficient in nitrogen, and are often deficient in phosphorus; few instances of potassium deficiency are reported, however.

A soil analysis is essential to determine the amount and type of fertilizer needed to revegetate a mine spoil, and the fertilizer requirements also depend to a great extent on what is to be planted. Grasses invariably need nitrogen, but do not necessarily respond to additions of phosphorus and potassium (Cook, Hyde, and Sims, 1974; Grandt, 1965); on the other hand, legumes need phosphorus but not nitrogen, since they are capable of fixing atmospheric nitrogen (Grandt, 1965; Mays, 1975), and the addition of nitrogen in fertilizer may even inhibit their germination (Dean et al., 1974). The Guide for Revegetating Bituminous Strip-Mine Spoils in Pennsylvania (1965) recommends, in the absence of a soil test, the annual application of at least 5.6 g/m^2 of nitrogen (50 lbs/acre), 11 g/m^2 (100 lbs/acre) of phosphoric acid and 11 g/m^2 (100 lbs/acre) of potash on herbaceous plots, with the nitrogen being eliminated on plots where legumes predominate.

The effect of fertilization on the survival and growth of trees is complex. Czapowskyj (1973) found that fertilization had little effect on the survival and growth of red pine and Japanese larch on anthracite breaker refuse in Pennsylvania. Funk and Krause (1965) found that fertilization hurt the survival of yellow poplar, white ash and white pine on Ohio mine spoils, but that it increased the growth rate of the trees that survived.

Nutrient requirements are generally lower for conifers than for hardwoods (Limstrom, 1960). The Guide for Revegetating Bituminous Strip-Mine Spoils in Pennsylvania (1965) recommends, in the absence of a soil test, 5.6 g/m^2 (50 lbs/acre) each of nitrogen, phosphoric acid and potash; on many spoils in the Midwest and West the latter two nutrients could probably be eliminated.

A good discussion of fertilizers and methods of mixing commercially available fertilizers to meet desired specifications are given in the Revegetation Manual (1966).

7.1.2.6 Planting -- Most revegetation guides indicate that early spring and early fall are the best seasons for planting, but differ in their choices between the two. Cook et al. (1974) suggest as a general rule that the best time to seed is just prior to the season that receives the most dependable precipitation. Other references suggest planting trees in the Spring (Guide for Revegetating..., 1965; Grandt, 1965; Limstrom, 1960; Revegetation Manual, 1966; Wheeler, 1965). Fall seedings are recommended for cool season grasses like fescue (Revegetation Manual, 1966), and in general for the Southwest and mountainous areas of the West where most precipitation occurs in the fall (Cook et al., 1974). Spring seedings are preferable for warm season grasses like weeping lovegrass, sorghum and millet, and for legumes, which may be winter-killed (Revegetation Manual, 1966). The Revegetation Manual (1966) recommends several seeding mixtures for different seasons.

The various guides to revegetation offer a number of miscellaneous suggestions regarding planting. Planting should be carried out immediately after grading (Revegetation, 1966). Legumes should be inoculated just prior to planting (Carter et al., 1974). Livestock should be kept from grazing on newly planted areas for at least two years (Revegetation Manual, 1966). Trees should be planted within two weeks after delivery, and must be kept moist prior to planting (Ibid.).

Seeding may be carried out by drilling or disking the seed onto a loose soil (pre-tilled, if necessary) and then, if possible, covering it or rolling or plowing it under. Broadcasting generally requires twice as much seed as drilling (Cook et al., 1974).

Dry broadcasting of seed alone or of seed and fertilizer can be accomplished effectively on level ground with a cyclone seeder, a blower attached to a lime-spreading truck, or an airplane (Revegetation Manual, 1966). Hydroseeding is an effective method of seeding, fertilizing and mulching slopes and highwalls (Ibid.).

Tree and shrub seedlings rather than seeds should generally be used, since most attempts to seed trees and shrubs directly in the field have been failures. Hand-planting of seedlings is generally necessary, although mechanical tree planters may be used on soil that is neither too steep nor too stony (Guide for Revegetating..., 1965). For all but steep slopes a spacing of 6 ft by 6 or 7 ft (1.8 m by 1.8 or 2.1 m) is frequently recommended, except for Christmas tree plantings, for which 7 ft x 7 or 8 ft (2.1 m x 2.1 or 2.4 m) plantings are recommended (Ibid.). Closer spacing is recommended for steep slopes where erosion control is a primary objective (Revegetation Manual, 1966). Seedlings in one row should be spaced to alternate with seedlings in adjacent rows (Ibid.).

7.1.2.7 Mulching -- The addition of a mulch--any material other than seed, plants, or chemical soil amendments--to a planted area serves several purposes:

a) Reduces evaporation from the soil.
b) Varies the surface temperature by absorbing more or less sunlight than the soil, according to whether a dark or light mulch is used.
c) Adds organic material to the soil.
d) Stabilizes areas subject to wind or water erosion, particularly steep slopes.

Mulches are strongly advised if the annual precipitation in the region to be revegetated is less than 46 cm (18 inches) (Cook et al., 1974. In seedings of grasses on strip mine spoil banks in Wyoming, the addition of mulch was found to be the most important factor in promoting survival (May et al., 1971).

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Mulching is essential on dark spoils, such as coal refuse banks, which if uncovered often reach temperatures too high to support plant growth (Schramm, 1966), and on steep banks which would otherwise be eroded. Rates of mulching should be increased on acidic spoils which have been limed, since root establishment on such spoils takes place almost entirely near the surface, the location most susceptible to evaporative drought (Revegetation Manual, 1966).

Several materials are commonly used as mulches. One of the best is straw, bound with an asphalt emulsion or a soil stabilizer to keep it from being carried away by wind or water. An application of 34 g/m^2 (300 lbs/acre) is recommended, with 75 ml/m^2 (80 gal/acre) (Revegetation Manual, 1966) to 0.28 ℓ/m^2 (300 gal/acre) (Cook et al., 1974) of asphalt emulsion or 28-37 ml/m^2 (30-40 gal/acre) of a soil stabilizer (Revegetation Manual, 1966) added as a binder. The problems with straw are its expense and the difficulty of spreading it on long outslopes. Also, it tends to be contaminated with grain and weed seed which germinate and compete with newly planted grass seedlings (Cook et al., 1974).

Shredded bark is another effective mulch, which unlike straw needs no binder to keep it in place, but like straw is difficult to spread on slopes. Application at 4.7-5.7 m^3/m^2 (25-30 cu yd/acre) is recommended (Revegetation Manual, 1966).

Shredded wood fiber or paper pulp applied at 0.17 kg/m^2 (1500 lbs/acre) is an effective mulch, principally in hydroseeding operations. The addition of a soil stabilizer in conjunction with this type of mulch on steep slopes is recommended. Wood fiber gives consistently good results except in areas where frost heaving or excessive water flow is a problem (Cook et al., 1974).

If straw or wood chips are used as mulches the rate of application of nitrogen fertilizer should be increased by about 4.5 g/m^2 (40 lb/acre), since some of the nitrogen is consumed in the decomposition of the mulch (Revegetation Manual, 1966).

7.1.3 Refuse Bank and Slurry Pond Reclamation

A thorough survey of the factors affecting growth on coal refuse is given by Schramm (1966), and discussions of coal refuse reclamation efforts are provided by Coalgate et al. (1973) and Kosowski (1973). Much of the ensuing material is based on these sources. The material to be presented is applicable only to the East and Midwest; no references to revegetation of refuse banks in the West have been encountered.

The general rules for grading set forth in Section 5.1.2 are applicable to refuse piles. Several authors stress the necessity of providing a slight grade at all points to prevent water impoundment, and of constructing furrows, ditches or culverts to allow drainage and erosion control (Brundage, 1974; Kosowski, 1973; Sorrell, 1974).

7.1.3.1 Vegetation of Bare Refuse -- The generally hostile chemical and physical environment and the extremely high surface temperatures which characterize coal wastes make revegetation without a soil cover extremely difficult to achieve. Surface temperatures, which may be as high as 74°C (166°F) following evaporative dessication of the refuse surface layers, may be principally responsible for the low probability of plant survival; invasions of such species as pines, birches and aspens have occurred in some cases, but usually only on steep northern slopes, which receive a minimum of sunlight (Schramm, 1966).

Vegetation has been established directly on refuse banks, but good or even reasonable coverage and growth has never been achieved, and a cover of not less than one foot of soil is recommended for all but small experimental refuse bank revegetation projects. On the other hand, successful revegetations of the fine wastes which constitute slurry ponds have been reported. Kosowski (1973) established a grass cover by liming and fertilizing heavily, seeding a mixture of 15 percent perennial ryegrass, 30 percent tall fescue, 15 percent reed canarygrass, 5 percent Ladino clover and 35 percent Balboa rye, and mulching with straw. (Planting details and cost data are given by Kosowski). An excellent stand of grass was achieved within nine months of seeding. Crownvetch was seeded, but did not germinate. The only problem encountered was the formation of an erosion ditch at one point; once better provisions for drainage were made, the revegetation proceeded smoothly.

An article entitled "How Green are Our Valleys" (1968) reports on the revegetation of a slurry pond near Idamay, West Virginia, where a hydroseeded cover of bluegrass, fescue, lespedeza and ryegrass is reportedly very well established.

There are several documented attempts to grow vegetation directly on refuse banks, most of which failed (Coalgate, 1973; Methods and Costs of Coal Refuse Disposal and Reclamation, 1973; Schimp, 1973; Schramm, 1966). The article "How Green are Our Valleys" (1968) suggests that hydroseeding has been used to establish a cover on refuse banks, but no details are given.

Schimp (1973) successfully germinated switchgrass, weeping lovegrass, yucca, bristly locust and Virginia pine on bare bituminous coal refuse; switchgrass was the only grass which survived beyond the first year.

Establishment of vegetation on bare refuse banks has been reported in other studies by Czapowskyj et al. (1968) (crownvetch planted on anthracite breaker refuse in Pennsylvania); Davidson (1974) (red pine, weeping lovegrass, tall fescue and Korean lespedeza on bituminous refuse in Pennsylvania) and Sorrell (1974) (tall fescue, perennial ryegrass and birdsfoot trefoil on a refuse pile in West Virginia).

The success of the first two efforts in achieving coverage of the refuse can at best be considered fair, and the third study reports results obtained only one month after planting, which precludes a proper evaluation. All of the authors found the addition of lime and mulch to be beneficial to the survival and growth of herbaceous species and to the growth of trees. Fertilization was necessary to establish grasses (Davidson, 1974) but did not appear to be beneficial to the establishment of crownvetch (Czapowskyj et al. 1968). Attempts to seed crownvetch rather than transplant it failed (Ibid.). Sopper et al. (1975) suggest that weeping lovegrass and deertongue grass are potentially good cover species for anthracite refuse banks.

7.1.3.2 Vegetation of Covered Refuse Piles -- Revegetations of refuse piles which were graded and covered with soil are described in a number of references, including Brundage (1974), Kosowski (1973), and Methods and Costs of Coal Refuse Disposal and Reclamation (1973). Test sites in these studies were located in Missouri, Illinois, West Virginia, Kentucky, Pennsylvania, Ohio and Kansas; results and recommendations are summarized in the paragraphs that follow.

7.1.3.2.1 Grading and covering the refuse pile -- The recommendations for grading given in Section 7.1.2 are applicable, except that the potentially negative effects of grading on plant growth provide less cause for concern if a cover is to be applied.

Brundage (1974) found that a nine inch soil cover was adequate to assure survival and growth on refuse piles in Missouri, and that additional cover did not lead to measurable improvement. He recommends a 30-46 cm (12-18 inch) cover to provide a margin of safety, and observes that mine spoil from adjacent spoil banks may be a better cover than soil from undisturbed areas. Kosowski (1973) also suggests a one-foot cover for plateaus, but indicates that a deeper cover might be needed on slopes. In Methods and Costs of Coal Refuse Disposal and Reclamation (1973), a one-foot cover is recommended for plateaus and a six foot (1.8 m) cover is suggested for slopes.

7.1.3.2.2 Species selection -- Most plantings on covered refuse banks are mixtures of long-lived perennial grasses (principally Kentucky (tall) fescue, some bromegrass, orchardgrass, red fescue, and weeping lovegrass), a short-lived grass for quick cover (usually perennial or annual ryegrass), and a legume (alfalfa, birdsfoot trefoil, crownvetch, Korean lespedeza, red clover, Sericea lespedeza or yellow sweetclover), the legume being included for its nitrogen-fixing ability.

Relatively few tree plantings are reported. White pine has been planted on covered banks in Kentucky (with poor results), Pennsylvania and West Virginia, and black locust has been planted in Kansas, Pennsylvania and West Virginia (Methods and Costs..., 1973). Brundage (1974) observed volunteer cottonwood and black willow trees on revegetated refuse piles in Missouri.

The potential of trees for long-term refuse bank stabilization has probably not yet been realized. Schramm (1966) observes that trees are the only species that can survive on highly acidic refuse piles in Pennsylvania. One inference is that grasses and legumes may become established on soil covers, but they will not succeed in extending their roots into the refuse. To achieve this objective, trees should be planted (when possible) which can tolerate the acidity and trace metal levels of the refuse; once established on the soil, they may be able to penetrate into the refuse to some extent, anchoring the soil cover and providing permanent stability.

Data for tree survival and growth on refuse--covered or bare--is scarce. Table 20 may be used as a guide for species selection.

7.1.3.2.3 Liming and fertilizing -- The recommendations given in Section 7.1.2 are applicable. Brundage (1974) used no lime or fertilizer in his reclamation of refuse piles in Missouri, but he had good soil to work with; in less hospitable regions like the Appalachians, soil amendments are invariably necessary. The use of fly ash or municipal sewage effluent as an alternative to limestone should be considered (See Section 7.1.3.3).

7.1.3.2.4 Planting and mulching -- The recommendations for planting given in Section 7.1.2 are applicable. Hydroseeding has been found to be a particularly effective technique for establishing grass-legume covers on slopes of refuse and spoil banks. Techniques for planting trees are summarized by Coalgate et al. (1973). A mulch cover is recommended for seedings of grasses and legumes.

7.1.3.3 Treatment of Refuse with Municipal Sewage Effluent and Fly Ash -- The use of treated municipal sludge and sewage effluent as additives to coal refuse has been studied by Sopper, Kardos and DiLissio (1975), who applied varying amounts of sludge and sewage effluent to samples of Pennsylvania anthracite refuse, and observed the effects of the additives on the survival and growth of trees (white spruce, hybrid poplar, black locust, red pine, white pine and Austrian pine), and various grasses and legumes. Similar studies on the survival and growth of perennial ryegrass and sorghum were carried out by Carter, Zimmerman and Kennedy (1973) using sludge and limestone treatments on coarse refuse and slurry from an Illinois mine.

Both studies show that municipal sludge is an effective source of plant nutrients, but that additional amendments is needed to neutralize the acidity of the refuse; sewage effluent served this purpose in the first study, and limestone achieved it in the second. Sludge was found to be a good source of nitrogen and phosphorus, but it also could raise the aluminum content of the soil to potentially toxic levels if applied in sufficient quantity (Sopper et al., 1975). Sewage effluent raised the pH of the refuse, and caused significant reductions in the level of extractable aluminum and iron (Ibid.).

While these results show that the use of sludge and sewage effluent has a good potential for use in refuse pile reclamation, no definite conclusions can be reached in the absence of field studies. The effects of these soil amendments on the surface temperature of the refuse, which Schramm (1966) regards as the principal growth-inhibiting factor, have not been determined, and the economic feasibility of transporting sludge to mine wastes which are not immediately adjacent to a sewage treatment plant must be examined.

Extensive research has been carried out by Capp and coworkers on the use of power plant fly ash as an additive to coal refuse (Capp and Gillmore, 1974; Adams, Capp and Gillmore, 1972; Capp and Adams, 1971). Fly ash is alkaline, and so raises the pH of the refuse; in addition, the fly ash improves the texture of the waste, increasing its porosity and moisture retention capacity, and adds some plant nutrients. The fly ash must be spread and thoroughly mixed with the waste material prior to planting, and after being seeded and fertilized, the planted areas should be mulched.

A mixture of tall fescue (35 percent), redtop (14 percent), orchard grass (18 percent), perennial ryegrass (28 percent) and birdsfoot trefoil (5 percent) is recommended for planting on fly ash-treated refuse. Capp and Gillmore (1974) evaluated several other grasses and legumes and found that intermediate wheatgrass, common goatsrue, flatpea, Blackwell and Carthage switchgrass, and yellow sweetclover show promise.

No data are provided for growth of trees on refuse treated with fly ash, but tests showed that trees planted on freshly treated surface mine spoils often suffered a high mortaility rate, which was reduced if several years elapsed between treatment with fly ash and planting. Crabapple and red oak had the best survival rate, and European alder had the best combination of survival and growth. Species which normally do well in spoils, such as Japanese larch, autumn olive, and black locust, failed on the fly ash-treated plots (Capp and Gillmore, 1974).

It appears that the use of fly ash as a soil amendment is a promising technique for refuse pile reclamation. If a grass cover is to be established, the planting may take place immediately following the addition of the fly ash, but if trees are planted, several years should be allowed (if possible) to elapse between treatment and planting; also, care should be taken to select species which are compatible with fly ash.

7.1.4 Surface Mine-Spoil Reclamation

General considerations concerning mine spoil revegetation have been presented in Section 7.1.2. The present section summarizes the results of revegetation attempts in the East, Midwest, and West--regions which differ significantly in climatic and agronomic characteristics and hence for which different species selections are generally appropriate.

Table 17 provides a listing of species which have been successfully used in spoil reclamations. This table should be used in conjunction with the plant catalog of Appendix B, which provides planting information and references to case studies for all species.

The sections that follow summarize species recommendations for the three principal geographical coal mining regions of the country.

7.1.4.1 Eastern States (Pennsylvania, Ohio, West Virginia, Virginia, Kentucky, Tennessee, Alabama) -- Several guides for revegetation in eastern states have been published, two of the best being the Guide for Revegetating Bituminous Strip-Mine Spoils in Pennsylvania (1965, rev. 1971) and the Revegetation Manual (1966), which is applicable principally to Kentucky. Suggestions for revegetation programs and comparative evaluations of different species are given in the references listed below:

Eastern States:	Planting Sites in the Northeast (1961), Ruffner (1965), Ruffner and Steiner (1973). The first of these references is not specifically applicable to mine spoils.
Kentucky:	Boyce and Merz (1959), Revegetation Manual (1966).
Ohio:	Finn (1958), Smith (1971), Struthers (1960).
Pennsylvania:	Miles et al. (1973), Guide for Revegetating... (1965). Hart and Byrnes (1960), Magnuson et al. (1969).
Virginia:	McCart et al. (1973).
West Virginia:	Ruffner (1966). (This reference evaluates a large number of species.)

Spoil acidity is frequently the principal growth-limiting factor in the East, and the plants which are most often recommended are those known to be acid-tolerant. Tables 18, 19, and 20 list such species.

On moderately acid to neutral spoils, tall fescue is by far the most frequently recommended perennial grass for the Northeast and Middle Atlantic states, and bermudagrass and bahiagrass are often recommended for the Southeast. Annual and perennial ryegrass and weeping lovegrass are often recommended for quick cover, with millet being recommended for this purpose in the Southeast and for summer plantings (which are generally inadvisable) in the North. The most popular legumes are birdsfoot trefoil, crownvetch, and sericea lespedeza; alfalfa, sweetclover and rye are less adaptable to acidic spoils, and so are recommended only under relatively good planting conditions.

The best shrubs for use on acidic planting sites appear to be autumn olive (Cardinal), bristly locust (Arnot), indigobush, and Japanese fleeceflower. For milder planting conditions, Amur and Tatarian honeysuckle, bicolor lespedeza (Natob), and multiflora rose are also recommended. Arnot bristly locust is particularly noted for its ability to provide rapidly a dense cover on steep or acidic spoil banks.

The hardwoods most often recommended are European black alder and black locust (both nitrogen-fixing species which provide rapid stabilization of spoil banks, and serve as nurses for other species). "Dominant stem" black locust appears to have all of the advantages of ordinary black locust and fewer disadvantages (Ruffner, 1965). (See Section 7.1.2.3.1).

Other frequently recommended hardwoods include European white birch, gray birch, river birch, and red oak, all of which are reportedly acid-tolerant. The survival of red oak is adversely affected by grading, and its initial growth rate is usually low. Hybrid poplars appear to be promising for use under a wide variety of conditions; several acid-resistant clones have been developed, and rates of survival and growth are generally good. Cottonwood, green and white ash, and sycamore--all of which have done very well in Midwestern plantings--have been used with only intermittent success in the East.

Numerous studies have been made of the relative performance of coniferous species on Eastern mine spoils. The most frequently recommended species are Virginia pine, Scotch pine, jack pine, white pine, and Japanese larch, and, for particularly acidic spoils, pitch pine and red pine. Ruffner (1966) found Virginia pine to be the most widely adaptable conifer of those he tested in West Virginia, and Davis and Melton (1963) obtained their most consistent results with Scotch pine in Pennsylvania. Wheeler (1965) found Japanese larch to be the fastest growing conifer tested in Pennsylvania. A number of authors note the excellent acid tolerance of red pine, but observe that is susceptibility to pine moth damage limits its usefulness. White pine has been included in many plantings, and is characterized by a relatively slow initial growth rate, but has a good long-range revegetation potential.

Conifers which have been used with mixed success include Austrian pine (reportedly acid tolerant), shortleaf pine, Norway spruce, and in the Southeast, loblolly pine.

7.1.4.2 Central States (Iowa, Illinois, Indiana, Kansas, Missouri, Oklahoma) -- An overview of the problems and economics of mine spoil reclamation in the Midwest is given by Carter *et al*. (1974). Species evaluations and recommendations are provided in several references.

Midwest:	Crowl (1962), Limstrom (1960), Ruffner (1965)
Illinois:	Boyce and Neebe (1959), Grandt and Lang (1958) Grant (1965)
Indiana:	Medvick (1973)
Iowa:	Lorio *et al*. (1964)
Kansas:	Geyer (1971)

Midwestern spoils tend to be less acidic than spoils in the East. Although highly toxic areas are often found, poor soil texture and inadequate drainage are more likely to be the principal growth-limiting factors.

Tall fescue is generally recommended for Midwestern plantings, although not as unanimously as it is in the East. Orchardgrass and smooth bromegrass are also recommended perennials, with orchardgrass being used more often by virtue of being easier to handle (Struthers, 1960). None of these species is well adapted to acidic spoils, although fescue is the best of the three in this respect. Redtop has been suggested for use on acidic spoils and to cover bare spots on previously planted areas (Struthers, 1960), but the life expectancy of this grass is only two to three years. For quick cover, perennial ryegrass is suggested for neutral spoils (Crowl, 1962; Struthers, 1960) and weeping lovegrass is recommended for acidic spoils (Struthers, 1960).

The most widely recommended legume for neutral sites is alfalfa, followed by birdsfoot trefoil and sweetclover. Birdsfoot trefoil reportedly provides the best cover, but is more difficult to establish than the other species. On acid spoils Korean and Sericea lespedezas have been used effectively.

Ruffner (1965) provides a large list of ratings of shrubs for Illinois, Indiana, Kentucky and Ohio. Species receiving good ratings in at least one experiment include indigobush, autumn olive (rated as acid-tolerant), Russian olive, bicolor lespedeza (acid-tolerant), *Japonica intermedia* lespedeza, Amur honeysuckle, and multiflora rose.

As in the East, black locust and/or European black alder are recommended for inclusion in almost all hardwood mixtures, with emphasis shifting to the latter tree in more recent plantings. Other hardwood species recommended for non-acidic spoils include green and white ash (moist sites, lower slopes and bottoms), cottonwood (not to be included in mixtures with black locust), silver maple, black walnut (can be seeded, best for mixed plantings rather than pure stands), sweetgum (warmer climates only), northern red oak (lower slopes, sands or loose loams), bur oak, sycamore (should not be planted with black locust), osage orange and yellow poplar (warmer climates only). Hybrid poplars apparently have not been tested in the Midwest, although the success achieved with hybrids in the East suggests their use.

Medvick (1973) recommends for non-sandy, non-acidic soils in Indiana mixed plantings of northern red oak, yellow poplar, sweetgum, black walnut, and either white ash or red or silver maple, or alternatively mixtures of cottonwood, sycamore, and European alder. He also recommends, for aesthetic purposes, mixing pines in with these plantings, particularly by roadsides. Smith (1971) suggests groups of three alternating rows: the first of black locust and European alder; the second (for pulpwood) of cottonwood, silver maple, sycamore, red gum, bigtooth aspen and autumn olive; and the third (for timber) of red oak, white oak, tulip tree, white ash and black walnut.

Coniferous plantings are generally preferable for acidic or sandy spoils. The conifers most frequently recommended include white pine (grows slowly, and should be planted in mixtures with more rapidly growing species), pitch and jack pine (acid tolerant species, need good drainage), Virginia pine (for wildlife cover only) and eastern red cedar (the only conifer which may be interplanted with black locust). The susceptibility of red pine to tip moth damage has discouraged its inclusion in plantings. Geyer (1971) recommends loblolly and shortleaf pines for Kansas spoils; both species are adapted to warm climates only, however, and shortleaf pine is susceptible to tip moth damage.

7.1.4.3 Western States (Montana, North and South Dakota, Wyoming, Colorado, Utah, Arizona, New Mexico) -- The best general reference for mine-spoil reclamation in the western states is Revegetation Guidelines for Surface Mined Areas by Cook, Hyde and Sims (1974); much of the material in the present section is based on this reference. The most comprehensive bibliography for mine spoil reclamation in the West (as well as the rest of the country) is Surface Mining and Mined Land Reclamation (1974), compiled by the Old West Regional Commission; and another large bibliography was prepared by Gifford, Dwyer and Norton (1972). References to reclamation efforts in high altitude areas in the Rocky Mountains are given by Berg (1974), Townsend (1974), Eaman (1974), and Steen and Berg (1975). Recent discussions of specific revegetation efforts are presented for New Mexico by Merkel and Currier (1971), for Montana by

Sindelar et al. (1973, 1974), for Colorado by Merkel, Hale and Sims (1973) and for Wyoming by Tresler (1974).

Mine spoils in the western states present more obstacles to revegetation than do spoils in any other region. Like Eastern spoils, spoils in the West have regions of high acidity, steep slopes, and low soil contents, and like Midwestern spoils, many spoils in the West have high clay contents, correspondingly poor drainage, and nitrogen deficiencies. In addition, western spoils are characterized by regions of high alkalinity and/or salinity, and high concentrations of potentially toxic trace metals. The principal limiting factor in the West is lack of moisture, however--total annual precipitations of less than 38 cm (15 inches) are commonplace, and in the northern regions most of the precipitation occurs as snow. In consequence, recommendations for plantings in the West show very little overlap with recommendations for the East and Midwest.

Most revegetation attempts have involved grasses, legumes and shrubs rather than trees, and the most frequently recommended species for all but desert areas in the Southwest are wheatgrasses. Crested wheatgrass is cited as being drought-resistant and suitable for steep slopes, but poor for wet, saline or alkaline spoils; it has been recommended for all Western regions but desert areas in Arizona and New Mexico and the alpine regions in Colorado (Cook et al., 1974). Western wheatgrass is suggested for Montana, Wyoming and the Dakotas; it is reportedly adaptable to moist, saline-alkaline spoils (Thornburg, 1975), and is suitable for heavier textured soils (Tresler, 1975), but may be hard to establish (Berg, 1975).

Tall wheatgrass has also been recommended for dry saline-alkaline spoils (Thornburg, 1975), and slender wheatgrass is suggested for use in mountainous regions (Cook et al., 1974), although its life expectancy may only be 4-5 years at high elevations (Berg, 1975). Intermediate, streambank, pubescent, thickspike, bearded and beardless wheatgrasses have also been used, with mixed results.

In the Northern Great Plains and the forested and subalpine regions to the south, smooth bromegrass has been used effectively; it is drought-resistant, and tends to dominate stands if fertilized intensively.

Other recommended grasses for cooler climates include tall, red and hard fescues, meadow and creeping foxtails and tufted hairgrass (mountainous regions), bluegrasses, orchardgrass and blue and sideoats grama. In the northern sandhills warm season grasses are suggested, including switchgrass, bluestem and Indiangrass (Cook et al., 1974). In the foothill regions of Utah, Colorado, Arizona and New Mexico wheatgrasses are recommended; Indian ricegrass is also suggested, but this grass is usually extremely difficult to germinate. Sand dropseed and alkali sacaton are recommended for growth on sandy spoils from northern New Mexico to northern Colorado (Ibid.).

Arid desert areas in New Mexico, Arizona, Utah and Western Colorado are probably the least hospitable areas to plant growth in the country, and as a rule the only species which can be grown in these areas are the species which are already there. Indian ricegrass and sand dropseed are among the grasses recommended by Cook et al. (1974) for these regions.

The only legume recommended for all but mountainous spoils is Russian wildrye, which has been successfully used in dry and saline-alkaline region plantings from Montana to New Mexico. In the mountains, alfalfa has been the only legume to perform consistently, although short-term success has been obtained with red and white clover (Townsend, 1974). Yellow sweetclover is recommended for the Colorado sandhills and foothills (Cook et al., 1974), and the Montana plains (Thornburg, 1975).

A variety of shrubs have been used in western mine spoil reclamations, almost invariably chosen from species native to the spoil regions. Big sagebrush and rabbitbrush are recommended for the northern plains, western foothills, and southwestern deserts, and fourwing saltbush and greasewood are also suggested for the deserts and for saline-alkaline regions (Cook et al., 1974). In studies in Montana, Thornburg (1975) reports good results on dry spoils with caragana, honeysuckle, Russian olive, skunkbush sumac and matrimony vine, and on wet and saline-alkaline spoils with buffaloberry, Russian olive and skunkbush sumac. May (1971) had success in Wyoming with Russian olive. Other recommended species for intermediate elevations include snowberry, chokecherry, serviceberry, and mountain mahogany (Cook et al., 1974). Ludeke (1973) provides descriptions of a large number of shrubs which may be suitable for mine-spoil reclamation in the southwestern desert.

The tree mentioned most often in connection with reclamation of Western mine spoils is the Ponderosa pine. In mountainous regions aspen, subalpine fir, Engelmann spruce and lodgepole pine may be transplanted (Cook et al., 1974). Douglas fir is native to mountainous regions, but no references to its use in mine spoil reclamation have been encountered.

7.1.5 Summary

1) A detailed land use plan for the spoil area to be reclaimed should be prepared before the mining operation begins and complete soil tests should be performed before and after mining operations have been completed. Stripping operations should be planned so that topsoil is stockpiled separately and used as a final cover, and pyritic shales and other potentially toxic overburden materials should be buried as deep as possible when the spoils are graded prior to planting.

2) If the spoil or refuse bank to be revegetated has a pH less than 3.5 and contains a substantial amount of pyritic shales, or if it has less than 20 percent of soil-sized particles (diameter less than 2 mm) and is unlikely to weather (decompose) to a significant extent, a soil cover should be provided prior to planting. A minimum cover of one foot (0.3 m) should be applied on plateaus, and up to six feet (1.8 m) should be applied on slopes. A cover is usually required for refuse bank reclamation and is often required for reclamation of slurry ponds, but is not usually essential for spoil revegetation.

3) Spoils should be graded to a slope of less than 25 percent for agricultural uses and to less than 35 percent for recreation and wildlife uses. A minimum grade of 1-2 percent should be provided to prevent water impoundment, and diversion furrows or ditches should be provided to allow drainage and to control erosion. Grading should be minimized on soils with clay contents above 15 percent to avoid overcompacting.

4) Grasses, legumes, shrubs and trees which have been used in mine spoil revegetation attempts are listed in Table 17. Shown in this table are species recommended for mine spoils in the East, Midwest, and West, and for acidic spoils, saline and alkaline spoils, arid

regions and warm and cool climates. This table should be used in conjunction with the plant catalog of Appendix B, which gives the scientific names of each plant, general planting recommendations, and results of mine-spoil revegetation efforts in which the plants were used. Summaries and discussions of species recommendations are given in Section 7.1.3 for refuse bank and slurry pond revegetation, and in Section 7.1.4 for mine-spoil revegetation.

5) The choice of whether to plant grasses and legumes or trees and shrubs is largely dictated by the desired land use--agriculture, pulpwood or timber production, or recreation and wildlife preservation. The chemical composition of the spoils and prevailing climatic conditions may impose restrictions on the choice, however. On highly acidic refuse and spoils, trees and shrubs may be the only species that can be established, while in arid desert regions the use of grasses and drought-tolerant shrubs may be mandatory.

6) The pH of acidic spoils should normally be raised to 5 or more prior to planting, but should be kept below 6 if conifers are to be planted. Agricultural limestone is the most commonly used neutralizing material; other alkaline materials which have been used on an experimental basis include power plant fly ash, municipal sewage effluent, and mined phosphate rock. The neutralizing material should be mixed into the top six inches (15 cm) of the spoil, or into the top twelve inches (30 cm) on particularly acidic spoils with high sulfur concentrations. It is advisable to allow six months to elapse between neutralization and planting.

7) Acid-tolerant plants should be used on acidic spoils, even following soil neturalization, since reoxidation of pyrites in the spoils may eventually reacidify the spoils. Tables 18, 19, and 20 list grasses, legumes, shrubs and trees which are known to be acid-tolerant.

8) Hydroseeding is an effective technique for establishing grass and legume covers on steep slopes. Planting rather than seeding is recommended for establishing tress and shrubs on slopes; the few woody species which have been established by direct seeding include black locust, bristly locust and shrub lespedezas.

9) In plantings of herbaceous covers, at least 5 to 10 percent legume should be included to fix and add atmospheric nitrogen to the soil. Legumes should always be inoculated with suitable microorganisms prior to planting.

10) The survival and growth of newly planted trees may be adversely affected by the presence of existing covers of certain grasses, including fescue and ryegrass. If trees are to be overplanted on a herbaceous plot, less competitive herbaceous species such as weeping lovegrass and legumes are preferable covers. Alternatively, a temporary herbaceous cover may be grown, killed and plowed under prior to tree planting.

11) Conifers and nitrogen-fixing hardwoods like European black alder and locust are the best species for rapid stabilization and growth on acidic spoils; hardwoods are generally preferable to conifers on neutral and calcareous spoils. Conifers are recommended for ridges and upper slopes, and hardwoods are preferable for lower slopes and valleys. Most conifers are unsuitable for growth on compact loams and clays.

12) Mixtures of tree species should be planted to maximize the likelihood of a successful reclamation. Using up to 25 percent of nitrogen-fixing nurse species such as black alder and black locust in tree plantings can be extremely effective; black locust should not be interplanted with conifers or with cottonwood or sycamore, however. Nurse species should not overtop the species they are supposed to be helping. A good method of avoiding this occurrence is to use nitrogen-fixing shrubs such as bristly locust and autumn olive as nurse species.

13) Trees should be planted in the spring. Cool season grasses like fescue should be planted in the fall; spring plantings are generally preferable for legumes and warm season grasses. In arid regions, plantings should be carried out just prior to the season that receives the most dependable precipitation.

14) Mulching is generally recommended, and strongly advised for arid regions and on dark spoils and refuse banks.

15) The establishment of vegetation directly on refuse banks is difficult to achieve, and a soil cover is recommended for all but small experimental refuse bank revegetation programs. Direct revegetation of

slurry ponds is possible, but requires extensive soil amendments, and careful provision for drainage and erosion control.

16) Treated municipal sewage sludge has been found to be an effective soil amendment in a number of studies. It provides both nitrogen and phosphorus, but may acidify the spoil and raise the aluminum content to a potentially toxic level, and so should be used with care.

17) No general catalog or revegetation guide is a substitute for the expertise of an agronomist or forester familiar with the area in which the revegetation is to be performed. The consulting services of an extension specialist affiliated with a local agricultural, Forest Service or Soil Conservation Service experiment station (Appendix C) should be used at all stages of planning and executing a land reclamation program.

Table 17. SPECIES USED FOR MINE-SPOIL REVEGETATION

Grasses	East	Midwest	West
Alkali Sacaton			Alk, D, S
Bahiagrass	+W		
Bermudagrass	++W, D, S		+W, D, S
Bluegrass	*C		+C
Bluestem	*		
Bottlebrush Squirreltail			N
Bromegrass (field, smooth)	+R, T	+	+D
Deertongue	+A		
Fescue	++	++	[illegible]
Foxtail			+C
Grama (blue, sideoats)			+D
Indian	*		
Indian Ricegrass			*
Millet	+R, T, W		
Needlegrass			*
Oatgrass (tall)	+	*	

+ - Recommended
++ - Highly recommended
* - Used
- - Failed
A - Recommended for acidic spoils (pH less than 5.5)
Alk - Recommended for alkaline spoils
C - Recommended for cooler climantes
D - Recommended for dry regions (less than 18 inches (46 cm) of precipitation per year)
N - Native or volunteer plant, not necessarily recommended
R - Recommended for rapid stabilization and erosion control
S - Recommended for saline spoils
T - Temporary or short-lived crop
W - Recommended for warmer climates
Blank- No information

Table 17 (cont'd)

Grasses	East	Midwest	West
Orchardgrass	+	++	+C
Povertygrass	N		
Prairie Sandreed Grass			+
Redtop	+C, T	+T	
Reed Canarygrass	*	+	*
Rye	+W		
Ryegrass	+C, R, T	+C, R, T	*C. R, T
Sand Dropseed			*
Sheep Sorrell	*		
Sorghum	+T		
Switchgrass	+W	+A	
Timothy	*		
Weeping Lovegrass	++A, R, W	++A, R, W	++A, R, W
Wheat		*T	
Wheatgrass	*		++Alk, D, S
Wildrye			*D

Table 17 (cont'd)

Legumes	East	Midwest	West
Alfalfa	+	++	+D
Birdsfoot Trefoil	++C	++C	+C
Cicer Milkvetch			*
Clover (red, white)	*		
Crownvetch	++C	+	
Flatpea	+A, C		
Kudzu	*	*	
Lespedeza (Sericea, Kobe, Korean)	++A	++A	
Narrowleaf Trefoil	+		
Sweetclover	+Alk		+D

Table 17 (cont'd)

Shrubs & Vines	East	Midwest	West
Arrowwood	+		
Black Chokeberry	+		
Bladder Senna	*		
Bristly Locust	++A, R	++A, R	
Buffaloberry			+Alk, S
Coralberry		*	
Greasewood			+Alk, D, S
Honeysuckle	+	+	+D
Indigobush	+A	+A	
Japanese Fleeceflower	*		
Juniper			*
Matrimony Vine			+Alk, D, S
Multiflora Rose	*		
Olive (autumn, Russian)	++A, Alk, R	+A	++Alk, D, S
Rabbitbrush			+D, W
Russian Thistle			N
Sagebrush (big)			+Alk, D, S
Saltbush			+Alk, D, S
Sassafras	N		
Scotch Broom	+A, W	+W	
Shadscale			+D, N
Silky Dogwood	+		
Sumac (fragrant, shining, skunkbush, smooth)	+A	+	++Alk, D, S

Table 17 (cont'd)

Trees	East	Midwest	West
Ailanthus		-	
Alder (black)	++A, R	++A, R	
Apple	*C		
Ash (green, white)	*	+	
Aspen	N		N, C
Austrian Pine	*A	*	
Bald Cypress	-		
Birch (gray, river, white)	+A		
Black Cherry	*A	*	*
Black Locust	++A, R	++A, R	
Black Walnut	*	*	
Caragana			+D
Cedar (red)		+	
Chestnut Oak	*	*	
Cottonwood	+	++	*
Crabapple	*		
Dogwood	*		
Douglas Fir	-		N, C
Elm (Siberian)		*	+D, S, Alk
Hazelnut	-		
Jack Pine	+A, C	+A	

Table 17 (cont'd)

Trees	East	Midwest	West
Japanese Black Pine	*		
Larch (European, Japanese)	+ (Japanese)		
Loblolly Pine	++W	++A, W	
Longleaf Pine	*W		
Maple (red, silver, sugar)	+A	*A	
Mugho Pine	+A		
Oak (bur, chestnut, red, white)	+A (red)	+	
Osage Orange		+	
Pitch Pine	*A	*	
Ponderosa Pine	-	-	*D
Poplar (hybrid, yellow)	++	+	
Redbud	*	+	
Red Pine	+A, C	+A, C	
Scotch Pine	+	+	*D
Shortleaf Pine	+	*	
Spanish Pine	*		
Spruce (Norway, red, white)	-	*	
Sweetgum	+	+	
Sycamore	++	++	
Virginia Pine	+A	+	
White Pine	+	*	
Willow (tall)	N	+	*
Yucca	+D		

Table 18. ACID-TOLERANT SPECIES: GRASSES AND LEGUMES

	pH<4.5	pH<5.5	References
Grasses			
Bentgrass	X	X	Bennett (1971), Goodman et al. (1973)
Bermudagrasses	X	X	Bennett (1971)
Charlottetown 80 (Barley)	X	X	Dean et al. (1971), Hill (1971)
Deertongue	X	X	Bennett (1971), McWilliams (1971), Miles et al. (1971), Ruffner (1965), Sopper et al. (1975)
Redtop		X	Bennett (1971), Carter et al. (1974), Crowl (1962), Guide for Revegetating (1965), Revegetation Manual (1966), Williams and Wallace (1973)
Ryegrass (annual and perennial)		X	Carter et al. (1974), Revegetation Manual (1966)
Switchgrass		X	Bennett (1971), Carter et al. (1974), Miles et a[illegible]73), Revegetation Manual (1966), Sopper et al. (1974[illegible]el and Berg (1968)
Tall (Ky) Fescue		X[a]	Bennett (1971), Carter et al. (1974), Guide for [illegible]tating (1965)
Weeping Lovegrass	X	X	Bennett (1971), Carter et al. (1974), Davidson ([illegible]), Fleming et al. (1974), Revegetation Manual (1966), Ruffner (1966), Sopper et al. (1975), Vogel (1970), Vogel and Berg (1968)
Legumes			
Birdsfoot Trefoil	X	X	Bennett (1971), Carter et al. (1974), Hill (1968), Revegetation Manual (1966), Sorrell (1974), Vogel and Berg (1968)

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[a] Tall fescue tolerates low pH but only in soils with little or no aluminum (Vogel and Berg, 1968).

Table 18 (cont'd)

	pH < 4.5	pH < 5.5	References
Flatpea (Wagner)		X	Bennett (1971), Miles *et al.* (1973), Ruffner and Stevens (1973)
Kobe Lespedeza	X	X	Berg and Vogel (1968), *Revegetation Manual* (1966), Vogel and Berg (1968)
Sericea Lespedeza	X	X	Bennett (1971), Carter *et al.* (1974), Dickens and Orr (1969), Guernsey (1970), Hill (1974), *Methods and Costs . . .* (1973), *Revegetation Manual* (1966), Ruffner (1965), Sorrell (1974), Vogel and Berg (1968)

Table 19. ACID-TOLERANT SPECIES: SHRUBS AND VINES

	pH < 4.5	pH < 5.5	References
Amur Honeysuckle		X	Carter *et al.* (1974), Crowl (1962), *Revegetation Manual* (1966), Ruffner (1966), Ruffner and Stevens (1973)
Autumn Olive	X	X	Carter *et al.* (1974), Magnuson and Kimball (1969), *Guide for Revegetating . . .* (1965), *Revegetation Manual* (1966), Ruffner (1965)
Bicolor (Natob) Lespedeza		X	Carter *et al.* (1974), Crowl (1962), *Guide for Revegetating . .* (1965), Ruffner (1965)
Bristly Locust	X	X	Carter *et al.* (1974), McWilliams (1970), *Revegetation Manual* (1966), Ruffner (1965), Sopper *et al.* (1975)
Flameleaf Sumac	X	X	Miles *et al.* (1973), Ruffner (1966)
Indigobush		X	Carter *et al.* (1974), Miles *et al.* (1973), *Revegetation Manual* (1966), Ruffner (1965, 1966), Ruffner and Stevens (1973)
Japanese Fleeceflower		X	*Revegetation Manual* (1966), Ruffner (1965), Ruffner and Stevens (1973)
Scotch Broom	X	X	Crowl (1962), Horn and Wood (1969), Ruffner (1965)
Shining Sumac		X	*Revegetation Manual* (1966), Ruffner (1965)

Table 20. ACID-TOLERANT SPECIES: TREES

	pH < 4.5	pH < 5.5	References
Ash (Green and White)		X	Knabe (1964), Revegetation Manual (1966)
Aspen	X	X	Knabe (1964)
Austrian Pine	X	X	Guide for Revegetating . . (1965), Horn and Ward (1969), Sopper et al. (1975)
Black Locust			Boyce and Neebe (1959), Carter et al. (1974), Crowl (1960), Czapowskyj (1970), Guide for Revegetating . . (1965), Limstrom (1960), Revegetation Manual (1966), Wheeler (1965)
Cottonwood		X	Dale (1963), Revegetation Manual (1966), Ruffner (1966)
European Alder	X	X	Carter et al. (1974), Czapowskyj (1970), Dale (1963), Guide for Revegetating . . (1966), Knabe (1964), Magnuson and Kimball (1969), Miles et al. (1973), Revegetation Manual (1966), Ruffner (1966), Wheeler (1965)
Gray Birch	X	X	Coalgate et al. (1973), Horn and Ward (1969)
Hybrid Poplar	X	X	Davis (1964), Eschner (1960), Jones (1973), Kendig (1973), Revegetation Manual (1966)
Jack Pine		X	Crowl (1962), Czapowskyj (1970), Czapowskyj and McQuilken (1966), Guide for Revegetating . . (1965), Hart and Byrnes (1960), Limstrom (1960), Lowry (1960), Magnuson and Kimball (1964), Wheeler (1965)
Japanese Birch		X	Czapowskyj (1970), Czapowskyj and McQuilken (1966), Guide for Revegetating . . . (1965), Magnuson and Kimball (1969), Wheeler (1965)
Loblolly Pine	X	X	Carter et al. (1974), Chapman (1967), Crowl (1962), Boyce and Neebe (1959), Dale (1963), Limstrom (1960), Plass (1968), Revegetation Manual (1966), Thor and Kring (1964)
Mugho Pine	X	X	Guide for Revegetating . . (1965), Miles et al. (1973), Ruffner (1966)

Table 20 (cont'd)

	pH < 4.5	pH < 5.5	References
Red Oak	X	X	*Guide for Revegetating . .* (1965), Hart and Byrnes (1960), Knabe (1964), Limstrom (1960), Ruffner (1966)
Red Pine	X	X	Coalgate *et al.* (1973), Crowl (1962), Czapowskyj and McQuilken (1966), *Guide for Revegetating . .* (1965), Hart and Byrnes (1960), Horn and Ward (1969), Limstrom (1960)
Scotch Pine	X	X	Brown (1962), Carter *et al.* (1974), Crowl (1962), Knabe (1964) Limstrom (1960), *Revegetation Manual* (1966)
Sycamore		X	Boyce and Neebe (1959), Carter *et al.* (1974), Crowl (1962), Dale (1963), Funk and Krause (1965), Plass (1968), *Revegetation Manual* (1966)
Virginia Pine	X	X	Boyce and Neebe (1959), Carter *et al.* (1974), Crowl (1972) Czapowskyj and McQuilken (1966), Dale (1963), *Guide for Revegetating . . .* (1965), Limstrom (1960), Miles *et al.* (1973), *Revegetation Manual* (1966), Ruffner (1966)
White Birch	X	X	Coalgate *et al.* (1973), *Guide for Revegetating . .* (1965), Horn and Ward (1969), Knabe (1964)

7.2 MINERAL TAILINGS

The mineral waste heaps produced by various mining operations consist of overburden spoils (the soil removed from above a buried mineral deposit), gangue and tailings (Table 1, Section 3). The composition of overburdens and gangue is relatively independent of the mineral being mined, and the discussion of coal mine-spoil revegetation given in Section 7.1 is equally applicable to these materials. On the other hand, tailings frequently contain a significant fraction of the mined mineral, and so present unique revegetation problems. Tailings are generally fine particles which are transported in slurries and stored in ponds. When these storage ponds dry, the potential for fugitive dust emissions is high, making wind stabilization a severe although often localized problem.

A common solution to the problem of revegetating tailings is to cover the tailings pond or pile with topsoil or other ground cover. This approach, which dominates current tailings revegetation programs has been discussed in Section 7.1. The pages that follow deal with the establishment of vegetation directly on the tailings without the assistance (and expense) of a soil cover.

Tailings are generally deficient in plant nutrients and water, and are often excessively saline, potentially toxic, of variable pH, and subject to severe wind erosion and sandblasting. Establishing a vegetative cover directly on tailings is as difficult as revegetating bare coal refuse; efforts to so are often abandoned and stabilization by other methods (such as a chemical cover) are implemented instead.

A primary requirement for vegetative stabilization of a tailings pile is to stabilize the tailings against wind erosion while the initial vegetation is being established. Combinations of mulches, chemical coatings, rapidly established plant covers and watering have been used to assist in achieving this objective.

Criteria for selecting suitable species and tailing amendments to foster growth and recommended planting and maintenance techniques are generally the same as described in Section 7.1. The sections that follow present considerations specific to individual minerals.

Table 21 lists some of the grasses, legumes, shrubs and trees that have been used or evaluated for the vegetative stabilization of mineral tailings. Few species have entries under more than one of the column headings, reflecting the importance of climate and geography upon vegetative growth.

7.2.1 Copper Tailings

Copper tailings are found primarily in the West from Montana to Arizona (Ludeke, 1974; Day and Ludeke, 1973; Nielson and Peterson, 1972), and in the Upper Peninsula of Michigan and in Ontario. The techniques and species used successfully at one site do not generally carry over to other sites because of differences in geography, climate and tailing composition.

7.2.1.1 Midwestern/Canadian Copper Tailings -- Michigan and Ontario copper tailings tend to be acidic, and even with a copper residue of only 1000-2000 ppm could present a toxic environment to vegetation when the pH is low. A key first step in revegetation is to lime the tailings to raise the pH to a point close to 7.0 (Young, 1969; Peters, 1970). Fertilizer amendments dictated by tailings analysis should be made in advance of seeding.

August or early fall is the preferred season for seeding because of better mositure availability. The initial seeding should be on the windward edge of the tailings to minimize wind blasting and burial of the emerging plants. A companion or nurse crop should be used to provide shade and reduce surface wind; snow fencing should be erected in exposed areas to reduce wind velocity (Young, 1969).

A grass seed mixture used successfully on the Copper Cliff tailings in Ontario is the following (Young, 1969):

12.5 lbs (5.7 kg) Canada Blue Grass
12.5 lbs (5.7 kg) Mixed Seed
    1 part Timothy
    2 parts Red Top
    1 part Kentucky Blue
    1 part Crested Wheat
    1 part Creeping Red Fescue

This grass seed mixture along with 16 lbs (7.3 kg) of either alfalfa or sweetclover and 1 1/2 bushels (53 dm^3) of oats was used to seed an acre (0.4 hm^2). Bromegrass was added at the rate of 10 lbs/acre (1.1 g/m^2) following this initial seeding. Annual maintenance includes the addition of lime and fertilizer as needed. The establishment of a maintenance-free revegetated area has not yet been reached (Erbisch, 1975).

7.2.1.2 Western U.S. Copper Tailings -- Copper tailings in Arizona were among the first copper tailings on which vegetation was successfully established. The most reliable technique for revegetation was to cover the tailings with 7.6 cm (3") or more of soil from the surrounding area [Ludeke, 1972].

A procedure for revegetation of uncovered tailings recommended by Nielson and Peterson (1972) begins with an analysis of the tailings, including measurement of pH, conductivity and salinity, and the concentration of nitrogen, phosphorus, potassium and sulfide within the tailings. When salinity is high (above 4 mmho/cm), water leaching must be carried out prior to planting. On acidic sites with large concentrations of heavy metals, lime must be used to raise the pH to at least 6. Repeated applications of lime may be required. Commercial fertilizers can be prescribed using conventional soil amendment criteria.

The second major recommendation of the Nielson/Peterson procedure is control of wind erosion and damage until plants are established. Chemical binding layers such as those described in Section 5 are effective and economical. The erection of physical wind barriers, such as snow fences and mulching are alternative but usually less effective approaches.

Another consideration is the need for adequate water. Irrigation is required on most Western sites and may have to be maintained even after plants are established. Not until native species take over the site can one abandon this maintenance step. The initial establishment of any species greatly speeds up the invasion of native species because seed is trapped and protected by the established vegetation.

On raw copper tailings in Southern Arizona, Ludeke (1973, 1975) has succeeded in establishing a variety of grasses, shrubs, trees, and cacti. Among the better performers are Buffel grass, blue panicgrass, bermudagrass and various saltbush species. These grasses were planted by hydroseeding on a south-facing tailing slope (1.5:1). Annual grasses (such as barley or rye for the winter; sudan or milo-maize during the summer) can also be used to establish quick, temporary stabilization that aids the invasion of natural species.

Species of cacti, desert trees and shrubs have also been successfully transplanted onto copper tailings. Even with grasses, vegetative plugging produces more complete long-term cover than broadcast seeding (Day and Ludeke, 1973).

Nielson and Peterson (1972) have evaluated a large number of species both in the laboratory and in the field, for stabilizing copper tailings at Magma, Utah. Of the species tested, tall wheatgrass has been the most durable. All species germinated and produced excellent stands but the hot dry, windy summer took a heavy toll, especially among the legumes. Sweetclover had a higher survival rate than alfalfa. Russian olive, hybrid poplar and European sage had the highest survival rate of the woody plants tested. Stands have persisted for 3 years and natural vegetation, chiefly tamarix, is currently invading the field test sites. The species planted are surviving with natural precipitation only, so that a permanent revegetation of these copper tailings appears to have been achieved. Fall seeding is recommended to establish a mature stand before the summer drought commences.

7.2.2 Uranium Tailings

Uranium mining takes place in the same general region as copper mining. Because of the radioactivity associated with the tailings, a strong argument exists for covering the tailings with soil before revegetating. Nonetheless, some work has been carried out on raw tailings.

Greenhouse studies by Nielson and Peterson (1972) show that "plants can be grown on uranium tailings if the pH, salinity, plant nutrients and moisture are corrected to, or maintained at, levels suitable for plant survival." Tall wheatgrass does well on Colorado uranium tailings (Nielson and Peterson, 1972; Berg, 1971). These tailings are always nitrogen deficient so that fertilizer must be added. Irrigation or sprinkling with water is also necessary to establish a vegetative stand.

Species established on uranium tailings at Durango, Colorado include smooth brome, sweetclover, cereal rye, wheat, barley, alfalfa, and various wheatgrasses (tall, intermediate, pubescent, western and crested) (Berg, 1971). These species were broadcast-seeded, fertilized with both nitrogen (as urea or ammonium sulfate) and superphosphate and sprinkled. Continued maintenance has been required, and invasion by native vegetation is limited so far.

7.2.3 Iron Tailings

Iron ore tailings are primarily a feature of the Northern Minnesota landscape, a by-product of the Mesabi range and its well known taconite deposits. Lesser mining operations are also found in the East.

7.2.3.1 Pennsylvania Iron Ore Tailings -- Revegetation of iron ore tailings in Pennsylvania has been described by Francis (1965, 1973, 1974), who hydroseeded 200 acres (81 hm^2) of inactive tailings with 115 lbs/acre (13 g/m^2) of the following seed mixture:

Switchgrass
Weeping lovegrass
Kentucky bluegrass
Perennial ryegrass
Korean lespedeza
Sericea lespedeza
Winter vetch
Crownvetch
Yellow sweetclover
Buffalo alfalfa

In addition, seedlings of various trees and shrubs were hand-planted at a density of 1500/acre (37/dam^2). The hydroseeding included a paper mulch, fertilizer and agricultural sulfur (to reduce the soil pH of 8.9). This treatment, completed in 1962, produced a permanent vegetative cover which has since survived and thrived without additional maintenance.

Some species--shortleaf pine, Japanese black pine, gray Douglas fir, concolor fir, and bristlecone pine--grew directly on the tailings without any stabilization, fertilizer or other amendments.

This small tailing site is located in the heart of some of the richest farmland in the United States, a fact which undoubtedly accounts for much of the success of this program.

7.2.3.2 Minnesota Taconite Tailings -- Large tailings basins characterize the Minnesota taconite regions. Many of these basins are active, containing a wet center which is fed from ongoing mill operations. The wet, water-covered basin does not present an erosion problem until it is full; however, the sloping dam sides and berms are dry and must be stabilized immediately against both air and water erosion. Cutting horizontal benches in the slopes reduces water runoff by creating ponds on the various benches which then either infiltrate or evaporate.

Hydroseeding of tailing slopes is a frequently recommended technique; however, for best results fertilizer should be incorporated into the top 10-13 cm (4-5 inches) of the tailing which hydroseeding does not do. If fertilizing is followed by a discing operation or, a Klodbuster treatment, the fertilizer, particularly the phosphorus amendment needed for plant root development, becomes better distributed. This treatment can then be followed by conventional planting and mulching. (Dickinson, 1975).

Legumes are particularly valuable because of their nitrogen fixing properties. Taconite tailings are generally alkaline, and hence ideal for legumes. Of legumes tested by Dickinson (1975), birdsfoot trefoil, alfalfa and sweetclover "showed the greatest promise".

Grasses are important for their root-forming ability and stabilizing effects. The best grasses tested by Dickinson (1975) on Minnesota taconite tailings were intermediate and western wheatgrasses, reed canary grass, smooth brome and hard fescues.

Two seed mixtures, containing both grasses and legumes, are used by Dickinson:

	lbs/acre	(g/m^2)		lbs/acre	(g/m^2)
Intermediate wheatgrass	15	1.7	Smooth Brome	20	2.2
Red fescue	15	1.7	Perennial rye grass	5	0.6
Alfalfa	10	1.1	Alfalfa	5	0.6
Birdsfoot Trefoil	5	0.6	Birdsfoot Trefoil	10	1.1
Total	45	5.1		40	4.5

These mixtures are hydroseeded onto the slopes, either together with fertilizer or following a separate fertilization step. Planting is done in either October or May. A mulch, preferably straw, is applied with a blower and held in place by asphalt "tac".

Woody plants such as red and jack pine and shrubs such as Russian olive, serviceberry and silverberry are planted after the tailing surface has been stabilized by the grasses and legumes.

Some planting of annual grasses such as barley, rye or millet on the flat peripheral regions of active basins is both worthwhile and relatively simple, since more conventional farming equipment can be used and conventional farming procedures can be followed. Dickinson (1975) has also successfully raised vegetables, such as squash, potatoes, carrots, radishes and beets, in these flat basin area.

Native vegetation is now invading the areas initially stabilized with grases and legumes and the establishment of a permanent, maintenance-free vegetative cover on taconite tailings seems to be well underway.

7.2.4 Other Metallic Ores

In general the experiences associated with revegetating copper, iron or uranium tailings apply to revegetating other mineral tailings. All tailings are likely to be toxic, nutrient-deficient, highly acidic or highly alkaline, excessively saline and of poor texture. Very few plants survive on such inhospitable substrates without proper leaching, fertilizing, liming and irrigation--at least during initial plant establishment.

The approach of developing a species or clone of a species that is exceptionally tolerant to a specific heavy metal has been followed by Goodman and coworkers in England (Goodman *et al*., 1973). They find, for example, that the grasses red fescue, hard fescue, bentgrass, *Anthosanthum odoratum**, *A. stolonifera** and *Silene maritina** are tolerant to lead and zinc. Multiple tolerance to two or three metals can probably be found or developed by growing species or collecting those that have developed on old metal mine sites. In Goodman's (1973) work, zinc tailings proved to be more toxic than either copper or steel-mill tailings.

In general, however, the search for a "super" species, capable of surviving and growing when other species cannot, is a long, expensive undertaking. Even when such a plant is identified or developed, the problem of acquiring sufficient seed or stock to cover large areas remains. The more popular and practical approach has been to accomodate the site to the requirements of the readily available vegetation.

Molybdenum tailings at Climax, Colorado have been studied in extensive laboratory tests and field tests by Berg *et al*. (1975). They find that leaching of soluble salts and the addition of lime and fertilizer are essential for successful revegetation. Cereal rye (*secale cereale*), provides satisfactory temporary stabilization but continued maintenance and amendment appear necessary for long-term stabilization.

Sand tailings and slimes resulting from gold mining operations in South Africa have been the subject of extensive revegetation studies (James, 1966; "Stabilizing Mine Dumps," 1968; Creswell, 1973). Presently recommended procedures include the construction of a windbreak from reed canes to protect individual plots of about 15' x 20' (4.6 m x 6.1 m), and liming the plots to adjust the pH to 6.5. Conventional seeding and fertilizing then establishes a grass mixture including both fast growing annuals and perennials. By the third season weeping lovegrass dominates in most plots. Eventually invaders and even the reeds move in to further stabilize the tailings. Some success with agricultural crops such as alfalfa and barley has also been demonstrated.

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*Scientific name used since species is not listed in Appendix B

7.2.5 Phosphate Slimes

Phosphate slimes constitute a unique problem for solution by vegetative methods. The overburden spoils and tailings from phosphate mining are generally not deficient in nutrients other than nitrogen. Indeed a major use of the phosphate rock being mined is as a source of agricultural phosphorus. Standard agricultural practices have been used to revegetate both phosphate spoils and tailings in Tennessee and Florida (Moorman, 1975).

The major environmental problem is not wind erosion but separation of the fine phosphatic clays from the water slurry. These particles are small enough to pass through 2 μm sieve openings and remain in suspension for long periods of time. Even in static tailings ponds the particles settle very slowly so that the proliferation of these slime pits, drying out by slow evaporation or settling processes in humid Florida, is now a growing environmental problem as well as a source of mineral loss (about one-third of the mined rock ends up in the slime pond (Florida Phosphate Slimes..., 1975).

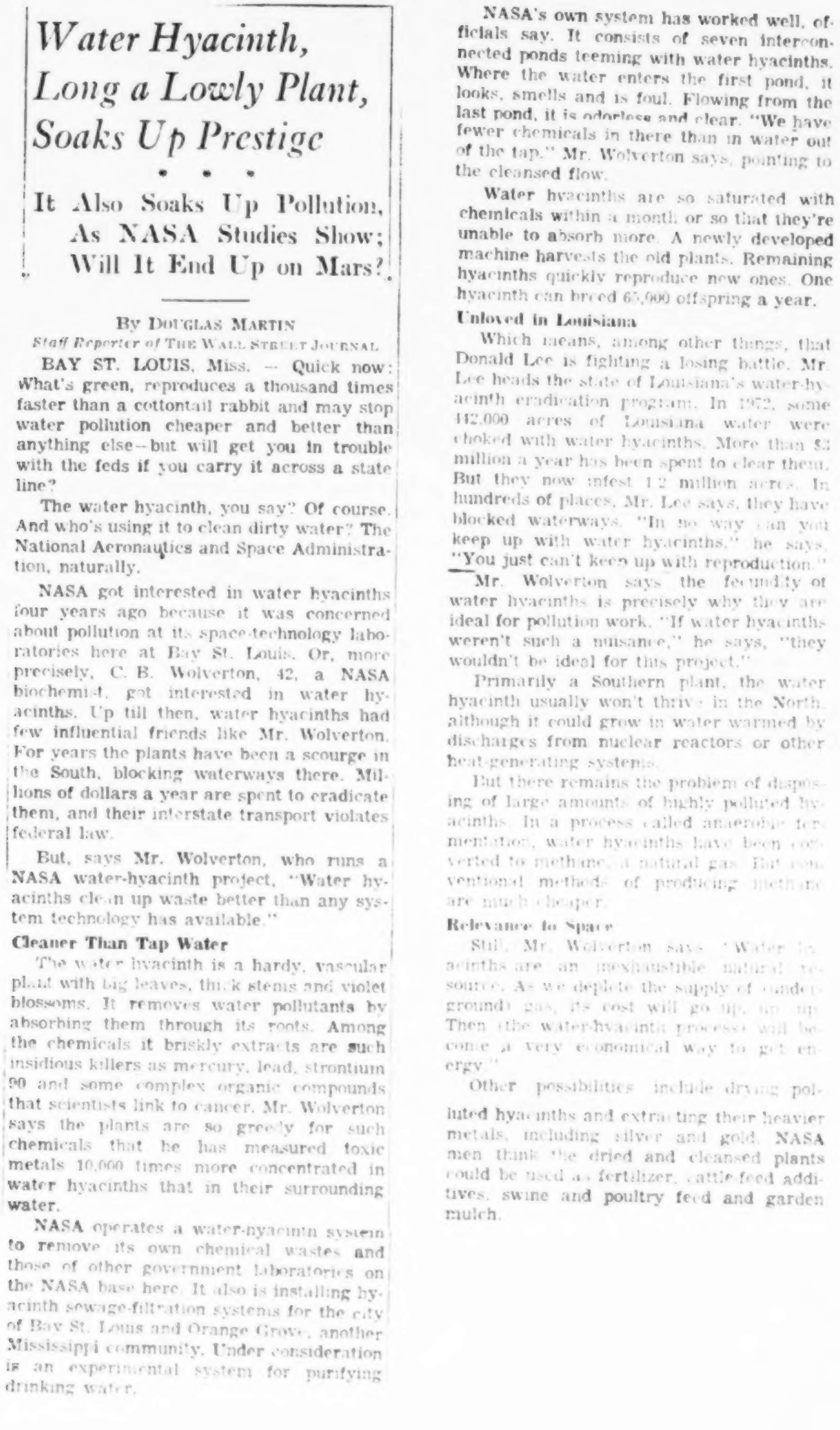
A vegetative solution to the dewatering of phosphate slime wastes consists of growing water hyacinths in them. Like any plant, hyacinths absorb water and transpire it to the atmosphere. Hyacinths seem to do it better than most and can increase the solids content of slurries as much in weeks as natural evaporation and settling processes do in years. Some ponds as old as 40 years, are still not dry and show little change with time.

Hyacinths are also useful for cleaning slurries and effluents but as the news item of Figure 15 reflects, are not always regarded as a blessing.

Water mint and water cress have also proved effective in dewatering tests at Salt Lake City (Dean, Havens, Harper and Rosenbaum, 1969).

7.2.6 Chemical-Vegetative Covers

A technique for establishing vegetative cover on exposed, inhospitable mineral tailings is the combination chemical/vegetative method developed by the Bureau of Mines at Salt Lake City (Dean, Havens and Glantz, 1974; Dean, Havens and Harper, 1969; Havens and Dean, 1969). This technique applicable to a wide variety of tailings and well suited to the dry,



Water Hyacinth, Long a Lowly Plant, Soaks Up Prestige

* * *

It Also Soaks Up Pollution, As NASA Studies Show; Will It End Up on Mars?

By DOUGLAS MARTIN
Staff Reporter of THE WALL STREET JOURNAL

BAY ST. LOUIS, Miss. -- Quick now: What's green, reproduces a thousand times faster than a cottontail rabbit and may stop water pollution cheaper and better than anything else--but will get you in trouble with the feds if you carry it across a state line?

The water hyacinth, you say? Of course. And who's using it to clean dirty water? The National Aeronautics and Space Administration, naturally.

NASA got interested in water hyacinths four years ago because it was concerned about pollution at its space-technology laboratories here at Bay St. Louis. Or, more precisely, C. B. Wolverton, 42, a NASA biochemist, got interested in water hyacinths. Up till then, water hyacinths had few influential friends like Mr. Wolverton. For years the plants have been a scourge in the South, blocking waterways there. Millions of dollars a year are spent to eradicate them, and their interstate transport violates federal law.

But, says Mr. Wolverton, who runs a NASA water-hyacinth project, "Water hyacinths clean up waste better than any system technology has available."

Cleaner Than Tap Water

The water hyacinth is a hardy, vascular plant with big leaves, thick stems and violet blossoms. It removes water pollutants by absorbing them through its roots. Among the chemicals it briskly extracts are such insidious killers as mercury, lead, strontium 90 and some complex organic compounds that scientists link to cancer. Mr. Wolverton says the plants are so greedy for such chemicals that he has measured toxic metals 10,000 times more concentrated in water hyacinths that in their surrounding water.

NASA operates a water-hyacinth system to remove its own chemical wastes and those of other government laboratories on the NASA base here. It also is installing hyacinth sewage-filtration systems for the city of Bay St. Louis and Orange Grove, another Mississippi community. Under consideration is an experimental system for purifying drinking water.

NASA's own system has worked well, officials say. It consists of seven interconnected ponds teeming with water hyacinths. Where the water enters the first pond, it looks, smells and is foul. Flowing from the last pond, it is odorless and clear. "We have fewer chemicals in there than in water out of the tap," Mr. Wolverton says, pointing to the cleansed flow.

Water hyacinths are so saturated with chemicals within a month or so that they're unable to absorb more. A newly developed machine harvests the old plants. Remaining hyacinths quickly reproduce new ones. One hyacinth can breed 65,000 offspring a year.

Unloved in Louisiana

Which means, among other things, that Donald Lee is fighting a losing battle. Mr. Lee heads the state of Louisiana's water-hyacinth eradication program. In 1972, some 142,000 acres of Louisiana water were choked with water hyacinths. More than $2 million a year has been spent to clear them. But they now infest 1.2 million acres. In hundreds of places, Mr. Lee says, they have blocked waterways. "In no way can you keep up with water hyacinths," he says. "You just can't keep up with reproduction."

Mr. Wolverton says the fecundity of water hyacinths is precisely why they are ideal for pollution work. "If water hyacinths weren't such a nuisance," he says, "they wouldn't be ideal for this project."

Primarily a Southern plant, the water hyacinth usually won't thrive in the North, although it could grow in water warmed by discharges from nuclear reactors or other heat-generating systems.

But there remains the problem of disposing of large amounts of highly polluted hyacinths. In a process called anaerobic fermentation, water hyacinths have been converted to methane, a natural gas. But conventional methods of producing methane are much cheaper.

Relevance to Space

Still, Mr. Wolverton says, "Water hyacinths are an inexhaustible natural resource. As we deplete the supply of (underground) gas, its cost will go up, up, up. Then (the water-hyacinth process) will become a very economical way to get energy."

Other possibilities include drying polluted hyacinths and extracting their heavier metals, including silver and gold. NASA men think the dried and cleansed plants could be used as fertilizer, cattle-feed additives, swine and poultry feed and garden mulch.

Figure 15. The Water Hyacinth (from the Wall Street Journal, Friday, August 22, 1975).

windy West, consists of applying a chemical coating to a freshly seeded and fertilized wet tailing surface. The chemical coating, such as Coherex (see Section 5), should restrict evaporation from the surface, although it must also be porous enough to allow air and moisture to penetrate to the tailings. The chemical itself cannot be toxic or physically inimical to the vegetation, but at the same time it should stabilize the surface against wind erosion so that the emerging plants are not physically damaged or buried before becoming established. Coherex has also been shown to possess the advantageous property of promoting seed germination and plant survival on saline copper tailings, apparently countering the toxic effects of the salts that normally exist in the tailings (Dean et al., 1974).

The chemical/vegetative method has been successful in establishing vegetation on copper tailings at high altitudes in Nevada. Six years after the seeding with a mixture of various wheatgrasses, Russian wild rye, alfalfas and clover, an ecological succession has occurred. Twenty-seven different plant species are now growing on the site, seventeen of which are invading native species. No irrigation or maintenance has been carried out since the initial seeding, and wind erosion is no problem in spite of the severe windstorms that often occur in the area (Dean et al., 1973)

Table 21. SPECIES RECOMMENDED FOR MINERAL TAILINGS RECLAMATION

Grasses	East	Midwest	West
Bahiagrass	D, P, W		
Barley			+Cu: Alk, S
Bentgrass (fine)			+
Bermudagrass			+Cu
Bluegrass			*U: C
Bromegrass		*Fe	+Cu: C
Buffel Grass	*P		+Cu: Alk, S
Fescue	*Fe	+Fe	+Cu: C
Indian Ricegrass			*0
Milomaize (see Sorghum)		*Fe	*Cu
Pangolagrass			*Al
Pubescent Wheatgrass			++0
Quack Grass			-Cu
Rye			*Cu
Ryegrass	*Fe: R, T		+Cu: C, T
Saltgrass			-Cu
Sorghum	*P		+Al, Cu: W
Switchgrass	*P		

+ - Recommended
++ - Highly recommended
* - Used
- - Failed
Al - Bauxite spoils
Alk - Recommended for alkaline spoils
C - Recommended for cooler climates
Cu - Copper tailings
D - Recommended for dry regions (less than 18 inches of precipitation per year)
Fe - Iron ore tailings
Mo - Molybdenum tailings
N - Native or volunteer plant, not necessarily recommended
O - Oil shale
P - Phosphate spoils
R - Recommended for rapid stabilization and erosion control
S - Recommended for saline spoils
T - Temporary or short-lived crop
U - Uranium spoils
V - Vanadium spoils
W - Recommended for warmer climate

Table 21 (cont'd)

Grasses	East	Midwest	West
Timothy		*Fe	
Weeping Lovegrass	++V: R		++Cu
Wheat			+Cu
Wheatgrass			++Cu, U, V: Alk, S
Wildrye (Russian)			+Cu: D

Legumes	East	Midwest	West
Alfalfa		+Fe, Cu	+Cu
Birdsfoot Trefoil		+Fe	+Cu: D, S
Clover	+P		
Sweetclover		+Fe	+Cu, V

Table 21 (cont'd)

Trees, Shrubs, & Vines	East	Midwest	West
Alder	+Fe		
Aspen			+Mo: C
Austrian Pine			*
Birch	+Fe: Alk		
Black Locust	+Fe	*Fe	
Blue Palo Verde			+Cu: Alk, D, S
Bristlecone Pine	+Fe		
Bristly Locust			+Cu
Cacti			+Cu: D, W
Caragana			+Cu
Cottonwood			+Cu
Creosote Bush			+Cu: Alk, D, S
Datura			+Cu: Alk, D, S
Desert Broom			+Cu: Alk, D, S
Desert Encelia			+Cu: Alk, D, S
Desert Tobacco			+Cu: Alk, D, S
Desert Willow			+Cu: Alk, D, S
Douglas Fir			-
Eucalyptus			+Cu: N, S
Greasewood			-Cu
Hopseed Bush			+Cu: Alk, D, S
Isenberg Bush			+Al
Jack Pine	+Fe		
Japanese Black Pine	*Fe		

Table 21 (cont'd)

Trees, Shrubs, & Vines	East	Midwest	West
Juniper			+Cu, Mo
Kochia			+Cu
Mesquite			+Cu: Alk, D, S
Myrtle			+Al
New Mexico Forestiera			+0
New Mexico Locust			++0
Olive (Russian)			+Cu, 0
Peru Pepper			+Cu: Alk, D
Poplar (hybrid)	++Fe		+Al, Cu
Rabbitbrush			+Cu: Alk, D, S
Red Pine		+Fe	
Ruby Sheepbush			+Cu: Alk, S
Russian Thistle			+Cu
Sagebrush (big)			+Cu: Alk, S
Saltbush			+Cu: Alk, D, S
Scouring Rush		Cu: N	
Shortleaf Pine	+Fe		
Spruce (Engelmann)			+Mo: C
Tamarisk			+Cu: Alk, S

7.3 SPENT OIL SHALE

Vegetative growth has not been established on untreated spent oil shale due to the excessive salinity of this material. Typical conductivities of spent shale are on the order of 15 mmhos/cm, where the upper limit for growth has been placed at 4 mmho/cm; consequently, raw spent shale must be leached before vegetation of any kind has any chance of survival (Harbart and Berg, 1974; Schmehl and McCaslin, 1973; Merkel, 1973; Cook, 1974). Alternative treatments, such as soil cover or mixing with adjacent soil, may be used; however, salt can contaminate the soil cover by capillary action so that such measures may not be permanent unless unusually thick covers are employed (Harbart and Berg, 1974).

Bloch and Kilburn (1973) have published a collection of shale revegetation studies. The papers include results of greenhouse and field experiments, economic analyses and environmental impact studies. An appendix to that report, reproduced here as Table 22, lists 68 species of grasses, legumes, shrubs that have been planted on various test plots.

A series of reports on various aspects of revegetating spent oil shales is being prepared by the Environmental Resources Center of Colorado State University, Ft. Collins, Colorado 80523, several of which have already been issued (Cook, 1974; Harbart and Berg, 1974; Sims and Redente, 1974; Steen and Berg, 1975). Other useful reports concerning the properties and uses of oil shale are *Disposal and Uses of Oil Shale Ash* (1970) and Robinson and Cook (1973).

7.3.1 Site Preparation and Maintenance

Before spent shale may be used as a plant growing medium, the concentration of soluble salts in the shale must be reduced to levels at which the measured electrical conductivity is less than 4 mmhos/cm. Forty-eight inches (120 cm) of irrigation water passing through the shale should be adequate for this purpose (Cook, 1974). For maximum irrigation efficiencies, the water should be applied at a rate low enough to avoid runoff but high enough to minimize evaporative losses.

Table 22. PLANTS GROWN IN PARACHUTE CREEK PROCESSED SHALE REVEGETATION PLOTS (Bloch and Kilburn, 1973).

Classification	Scientific name	Common Name
	GRASSES	
Nat	Agropyron cristatum (L.) Gaertn.	fairway wheatgrass
N (PC)	A. dasystachyum (Hook.) Scribn.	thickspike wheatgrass
Nat (PC)	A. desertorum (Fisch.) Schult.	crested wheatgrass
Exotic	A. elongatum Host.	tall wheatgrass
N	Agropyron griffithsi Scribn. & Smith	Griffith's wheatgrass
Exotic	A. intermedium (Host) Beauv.	intermediate wheatgrass
N (PC)	A. riparium var. sodar Scribn. & Smith	streambank wheatgrass
N (PC)	A. smithii Rydb.	western wheatgrass
Exotic	A. trichophorum (Link) Richt.	pubescent wheatgrass
Exotic	Bromus inermis Leyss.	smooth brome
Exotic	Dactylis glomerata L.	orchard grass
N (PC)	Elymus cinereus Scribn & Merr.	basin wildrye
Exotic	E. junceus Fisch.	Russian wildrye
N (PC)	E. salinus Jones	salina wildrye
N	Festuca arizonica Vasey.	Arizona fescue
N	F. ovina L.	sheep fescue
Exotic	Festuca ovina var. duriuscula (L.) Koch.	hand fescue
Exotic	Lolium perenne L.	perennial rye
N (PC)	Oryzopsis hymenoides (R. & S.) Ricker	Indian ricegrass
N (PC)	Poa ampla Merr.	big bluegrass
Nat (PC)	P. pratensis L.	Kentucky bluegrass
N (PC)	Sporobolus airoides (Torr.)	alkali sacaton
N	S. cryptandrus (Torr.) A. Gray	sand dropseed
N (PC)	Stipa comata Trin. & Rupr.	needle and thread
	FORBS	
N (PC)	Achillea lanulosa Nutt.	yarrow
Exotic	Astragalus cicer Dougl. ex Hook	cicer milkvetch
Exotic	A. falcatus Lam.	sickle milkvetch
Exotic	Coronilla varia L.	crownvetch
N	Cowania stansburiana Torr.	cliffrose
N	Dalea purpea Vent.	dalea
N	Fallugia paradoxa (D. Don) Endl.	Apache plume
Exotic	Medicago sativa var. Ladak L.	alfalfa
Exotic	Melilotus alba Desr.	sweetclover (white)
Exotic	M. officinalis (L.) Lam.	sweetclover (yellow)
N (PC)	Penstemon strictus Benth.	Rocky Mtn. penstemon
N (PC)	Rosa sp.	wild rose
Nat (PC)	Salsola Kali L.	Russian thistle
N	Yucca sp.	yucca

Table 22 (cont'd)

Classification	SHRUBS Scientific name	Common Name
N (PC)	Amelanchier utahensis Koehne	Serviceberry
N (PC)	Artemisia tridentata Nutt.	big sagebrush
N (PC)	Atriplex confertifolia (Torr. & Fremon) S. Wats	shadscale saltbush
N (PC)	A. canescens (Pursh) Nutt.	fourwing saltbush
N (PC)	A. nuttallii S. Wats	Nuttall's saltbush
	Baccharis sp.	baccharis
Exotic	Caragana arborescens Lam.	caragana
N (PC)	Cercocarpus montanus Raf.	mountain mahogany
N (PC)	Chrysothamnus nauseosus (Pall) Britt.	rubber rabbitbrush
N (PC)	Clematis ligusticifolia Nutt.	Western virginsbower
Exotic	Colutea arborescens L.	common bladder senna
N	Cowania stansburiana Torr.	cliffrose
N	C. nauseosus var. graveolens (Nutt.) H.C.	rabbitbrush
Nat	Eleagnus angustifolia L.	Russian olive
N	Forestiera neomexicana A. Gray	New Mexico forestiera
N	Kochia vestita (S. Wats) Rydb.	desert molly
	Mahonia sp.	Oregon grape
N (PC)	Populus angustifolia James	narrowleaf cottonwood
N	P. sargentii Dode	broadleaf cottonwood
N	Purshia glandulosa Curran	desert bitterbrush
N (PC)	P. tridentata (Pursh) DC.	antelope bitterbrush
N (PC)	Quercus gambelii Nutt.	Gambel's oak
N (PC)	Rhus trilobata Nutt.	skunkbush
N	Robinia neomexicana A. Gray	New Mexico locust
Exotic	Salvia carnosa Dougl.	purple sage
N (PC)	Sarcobatus vermiculatus (Hook) Torr.	greasewood
N (PC)	Symphoricarpos oreophilus A. Gray	mountain snowberry
	TREES	
N (PC)	Juniperus scopulorum Sarg.	Rocky Mountain juniper
N	Picea engelmannii (Parry) Engelm.	Engelmann spruce
Exotic	Salix sp.	golden willow
Exotic	Ulmus pumila L.	Siberian elm

Key to Classification:

N Native to Colorado
Nat Naturalized
(PC) Native to Parachute Creek area

The leaching can be performed by sprinkling (Cook, 1974), which may also serve to maintain the vegetation on those sites subject to periodic droughts, or by some form of drip irrigation (Bengston, 1975).

Nitrogen and phosphorus deficiencies exist at all sites and must be corrected by fertilizer. If legumes do not become part of the vegetative stand, continued addition of nitrogen will most likely be required.

Harbart and Berg (1974), report relatively poor performance of vegetation on sites facing the south or southwest in the lower and mid-elevations of the Colorado oil shale region. Surface temperatures in the summer are significantly higher on such slopes, leading to a large water requirement, (Cook, 1974). Sheltering heaps of spent shale on their south and southwest-facing sides could be an inexpensive but important step before a vegetatiion program is undertaken.

7.3.2 Species Selection

The species selected for revegetation should consist of a mix of grasses, forbs, shrubs and trees. Table 22, reproduced from Bloch and Kilburn (1973), lists plants that have been grown in a specific experimental plot of spent shale in Parachute Creek, Colorado.

Of the species listed in Table 22 Merkel (1973) rated pubescent wheatgrass as the best performer among the grasses on 100 percent spent shale as well as in various shale/soil mixtures. New Mexico locust did best among the shrubs, followed by New Mexico forestiera and Russian olive. Baker and Duffield (1973) identified their most successful grasses as alkali sacaton, Russian wildrye and crested wheatgrass followed by Indian ricegrass, sand dropseed and streambank wheatgrass. Among the shrubs they tested, fourwing saltbush did the best followed by desert molly. Streambank wheatgrass and western wheatgrass did better when seeded in the spring. Woody plants should be transplanted.

At another location--the Piceance Basin in Colorado--Harbart and Berg (1974) experienced fair to poor establishment of such grasses as western wheatgrass and Indian ricegrass on their experimental plots of TOSCO process spent shale. They attributed this disappointing performance to low seeding rates and competition from barley which germinated from seeds in the mulch.

The shrubs and legumes seeded by Harbart and Berg did better, establishing fair to good stands. The best performers were big sagebrush followed by mountain mahogany and bitterbrush among the shrubs; Utah sweet vetch and various pentstemons among the legumes. All species were seeded, unlike the woody species evaluated by Merkel (1973) and by Baker and Duffield (1973), which were for the most part transplanted.

7.3.3 Present Status

Vegetative stabilization of spent shale is an active area of contemporary research. What has been shown is that various site preparation steps may render spent shale capable of supporting vegetation in the short run. Long-term success is not yet documented because serious investigations of this problem began only 10 years ago. No commercial scale action is underway; all field results reported are from experimental plots set up in the oil shale regions.

Methods of covering spent shale with soil (including rock) or mixing the surface shale with various volumes of soil are also being studied as alternative methods for stabilizing spent shale.

7.4 SAND AND GRAVEL PITS

7.4.1 Planning and Site Preparation

A survey of environmental problems and land rehabilitation practices associated with sand and gravel extraction operations is given by Schellie and Rogier (1963). Much of the material that follows is based on this reference.

The tailings (refuse) from sand and gravel processing and the subsoil which constitutes most of the overburden are generally deficient in nutrients and poor in texture. The recommended extraction procedure is to strip and stockpile the topsoil separately, and to use it as a final cover for land to be revegetated. In addition, the porosity and consequent poor moisture retention capacity of sand and gravel make it advisable to put a layer of a clay or other fine subsoil material below the topsoil, if such a material can conveniently be isolated during the stripping operation.

The extent of the site grading which must be carried out after extraction operations have been completed varies considerably with the intended use of the land. Schellie and Rogier (1973) give a large number of potential uses for worked-out extraction sites, along with grading recommendations for each use. Several suggested maximum grades are 0 percent for building construction, 1 percent for athletic fields, 10 percent for picnic and lawn areas, 25 percent for hiking trails, and 50 percent for ground cover areas.

A complete soil test prior to planting is an essential part of a revegetation program, both to serve as an aid in species selection and to determine soil amendments which might be needed. The porosity of sandy soils frequently leads to leaching away of nitrogen and potassium by rainfall or irrigation, so that the periodic replenishment of these two elements is likely to be required. Phosphorus tends to be readily immobilized, and so is less subject to washout.

The addition of humus (organic matter) to coarse soils prior to planting is generally advisable, both to improve the soil texture and to provide nutrients. Schellie and Rogier (1963) suggest using decayed plant material (muck or peat) for this purpose; consideration should also be given to the use of treated municipal sewage sludge, which has been found quite effective in coal and mineral spoil revegetation (See Section 7.1.2). An alternative means of providing organic nutrients is to plant a quick cover crop and to plow it under after it has become established. Legumes are suggested for this purpose, since they also fix atmospheric nitrogen and add it to the soil; particular species recommended include alfalfa, soybeans, sweetclover and red clover.

Finally, neutralization is often required to bring the soil pH to the optimal range for growth of the selected plant species. Agricultural limestone is usually used to raise the pH of acid soils; other alkaline materials which may be used for this purpose include municipal sewage effluent and power plant fly ash (See Section 6.1.2). The pH of alkaline soils can be lowered somewhat by the addition of humus, and to a greater extent by adding sulfur.

7.4.2 Species Selection

Schellie and Rogier (1963) give a large list of trees, shrubs and grasses adaptable to different regions of the United States. The intended use of this list is unclear, however; there is no indication that the listed species are particularly well adapted to sandy soils, and many of the species recommended for growth in sandy soils by such references as Limstrom (1960) and Medvick (1973) are not listed. The presumption appears to be that topsoil and nutrients may always be applied in amounts sufficient for the choice of plant species to be made entirely on the basis of landscaping considerations.

Relatively few references to species suitable for growth directly on sand and gravel have been encountered in the literature. Several authors suggest weeping lovegrass for this purpose (Dalrymple, 1968; Ruffner and Steiner, 1973; Struthers, 1960). This grass needs at least 15-20 inches (38-51 cm) of precipitation per year, and begins to die out after 3-5 years (Cresswell, 1973). Other sand-tolerant grasses include coastal panicgrass, beachgrass (Ruffner and Steiner, 1973) and sand dropseed (Cook et al. 1974). Jones (1973) proposes growing hybrid poplars in gravel pits, and notes that native cottonwoods which volunteer on gravel pits generally do well. Graetz (1973) observes that Eastern red cedar, Japanese black pine, live oak and yucca do well on sandy soils. Crowl (1962) makes the same observation about jack pine, and Goldfinger (1971) recommends scotch pine.

A large body of information exists on the establishment of vegetation on beaches and in desert areas; it is reasonable to assume that the species recommended for use in these areas have a good potential for use in sand and gravel pit reclamation. The most comprehensive reference to beach vegetation is the document *Dune Formation and Stabilization of Vegetation and Planting* by Davis (1960), which lists and discusses hundreds of species adaptable to coastal areas. Scarfo (1973) also lists many species suitable for seaside plantings. Other useful information about beach vegetation is contained in articles by Graetz (1973), Harbaz et al. (1965), and Woodhouse et al. (1967, 1968).

Several references cite the use of American beachgrass for dune stabilization (Blake *et al.*, 1973; Davis, 1960; Woodhouse and Hanes, 1967). This is a hardy salt-resistant grass which thrives along the eastern shoreline from New England to South Carolina, and has also been used in plantings along the Oregon and Washington coasts (Davis, 1960). Below North Carolina, seaoats is the dominant dune grass, and saltmeadow cordgrass (*Spartina patens*) grows extensively in sand flats and dunes away from the shoreline, and in salt marshes throughout the East (Woodhouse and Hanes, 1967). Bermudagrass is recommended for revegetation of sandy areas in warmer climates (Davis, 1960). Davis also cites successful plantings of shrubs and trees that have been found to be acid-tolerant in coal mine spoil revegetations, including black locust, red oak, black willow, scotch broom, black alder, various pines and Russian olive. Davis (1960) and Graetz (1973) both cite the adaptability of northern bayberry to dune areas in the East.

Species which have been found suitable for mine-spoil revegetation in desert areas in the Southwest should also be suitable for sand and gravel pit reclamation in warm, arid climates. The references on mine-spoil revegetation in the West cited in Section 7.1.4, particularly those of Cook, Hyde and Sims (1974) and Ludeke (1973), should be valuable sources of information in this regard. In addition to the species already mentioned in this section, consideration should be given to wheatgrass, switchgrass, bluestem, indiangrass, indian ricegrass, sagebrush, rabbitbrush, fourwing saltbush and greasewood, and in cooler climates caragana, skunkbush sumac, honeysuckle and matrimony vine (Cook *et al.*, 1974; Thornburg, 1975).

8.0 REFERENCES

Adams, L.M., J.P. Capp, and D.W. Gillmore. Coal Mine Spoil and Refuse Reclamation with Powerplant Fly Ash. J. of Waste Recycling, 13, No.6, 20-26, (1972).

Agricultural Research Service. Wind Erosion Checked with Feedlot Waste. Soil Conservation 40(5):15, December 1974.

Aharrah, Ernest C. and Richard T. Hartman, Survival and Growth of Red Pine on Coal Spoil and Undisturbed Soil in Western Pennsylvania. in Ecology and Reclamation of Devastated Land. Vol.1, R.J. Hutnik and G. Davis, Eds., Gordon and Breach, New York (1973). pp.429-444.

Aleshin, Eugene, Ed. Proceedings of the Fourth Mineral Waste Utilization Symposium. Chicago, Ill., May 7-8, 1974.

Alvarez, Helen, John A. Ludwig and K.T. Harper. Factors Influencing Plant Colonization of Mine Dumps at Park City, Utah. American Midland Naturalist, 92 (1), 1 (1974).

Anderson, Floyd G. and Robert L. Beatty. Dust Control in Mining, Tunneling, and Quarrying in the United States, 1961 through 1967. U.S. Dept. of the Interior, Bureau of Mines, March, 1969, IC 8408.

Antonovics, Janis. Personal Communication. Botany Dept., Duke University, Durham, N. C., 1975.

Antonovics, Janis and A.D. Bradshaw. Evoluation in Closely Adjacent Plant Populations. VIII. Clinal Patterns at a Mine Boundary. Heredity, 25(3), 349 (1970).

Armiger, W.H., J.N. Jones, O.L. Bennett. Rock Phosphate as an Aid in Revegetation of Acid Strip Mine Spoils. Presented at the 1975 Annual Meeting, American Society of Agronomy with Southern Association of Agricultural Scientists, New Orleans, La. Feb. 2-5, 1975.

Arnett, R.H. and D.C. Braungart. An Introduction to Plant Biology. St. Louis, Missouri, C.V. Mosby Co. 1970. 479 p.

Ashby, William C. and Malchus B. Baker, Jr. Soil Nutrients and Tree Growth under Black Locust and Shortleaf Pine Overstories in Strip-Mine Plantings. J. Forestry, 66 (1), 67(1968).

Ashley, Roger H. The Invasion and Development of Natural Vegetation on Spoil Banks in Central Pennsylvania. Master of Forestry Thesis. . Pennsylvania State University (1950).

Atkins, M.D. Conservation Plant Materials for the Great Plains. J. Soil and Water Cons., 17, 199 (1962).

Atwood, Mark T. Colony Oil Shale Development at Parachute Creek, Colorado. Presented at the Environmental Protection Agency Symposium on Environmental Aspects of Fuel Conversion Technology. St. Louis, Mo. May 13-16, 1974. pp.1-13.

Augustine, Marshall T., Jos. H. Vaden and Charles D. Baker. Evaluation of Plants Used Vegetating Strip-Mine Spoil in the Lonesome Pine Soil Conservation District of Virginia. U.S. Soil Conservation Service, Richmond, Va. 1964.

Automated Stockpile Sprinkling System, National Crushed Stone Assoc., 1415 Elliot Place, NW, Washington, D.C. 20007.

Bailey, Jack C. "Progress in Stabilization of Industrial and Mineral Wastes" Endeavor *64*, 1967.

Bailey, H.L. *The Standard Cyclopedia of Horticulture*, I, II, III, The MacMillian Co., New York, 1942.

Baker, E.P. and W. J. Duffield. 1973 Annual Revegetation Report, in *Processed Shale Revegetation Studies 1965-1973*, M.B. Block and P.D. Kilburn, eds., Colony Develop. Operation, Atlantic Richfield Co. December 1973.

Balasko, John A. Plant and Spoil Characteristics Affecting Surface Mine Revegetation, *Proceedings of the Revegetation and Economic Use of Surface-Mined Land and Mine Refuse*, Pipestream State Park, W. Va., Dec. 2-4, 1971.

Barnett, A.P. Using Perennial Grapes and Legumes to Control Runoff and Erosion. J. Soil and Water Conservation, 20, 212 (1965).

Barnhisel, R.I. Lime and Fertilizer Recommendations for Reclamation of Surface-Mined Spoils. Univ. of Kentucky, Dept. of Agronomy, AGR-40. March, 1975.

Barnhisel, R.I. Sampling Surface-Mined Coal Spoils. AGR-41. March, 1975.

Bates, C.G. Shelterbelt Influences: General Description of Studies Made. F. Forestry 43: 86-92, 1945.

Bauer, Hermann J. Ten Years' Studies of Biocenological Succession in the Excavated Mines of the Cologne Lignite District. In: Ecology and Reclamation of Devastated Land, R.J. Hutnik and Grant Davis (eds.). New York. Gordon and Breach, Inc., 1973. p. 271-283.

Beard, James B. Turfgrass: Science and Culture. Englewood Cliffs, N.J., Printice-Hall, Inc. 1973. 658 p.

Beasley, R.P. Erosion and Sediment Pollution Control. Iowa State Univ. Press, Iowa 50010 (1972). p.37.

Becker, C.B., D.B. Emerson and M.A. Nawrocki. Joint Construction Sediment Control Project. EPA-660/2-73-035, April 1974.

Bengston, G.W., S.E. Allen, D.A. Mays and T.G. Zarger, Use of Fertilizers to Speed Pine Establishment in Reclaimed Coal Mine Spoil in Northeastern Alabama; I. Greenhouse Experiments in Ecology and Reclamation of Devastated Land, Vol2., R.J. Hutnik and G. Davis, Eds., Gordon and Breach, New York (1973). pp. 199-225.

Berg, W.A. Plant-toxic Chemicals in Acid Spoils. Proc. of Coal Mine Spoil Reclamation Symposium, Oct. 11-14, 1965, Penn. State Univ., pp.91-96.

Berg, W.A. and Vogel, W.G. Manganese Toxicity of Legumes Seeded in Kentucky Strip-Mine Spoils. U.S. Forest Service Research Paper NE-119 (1968).

Berg, W.A., Grasses and Legumes for Revegetation of Disturbed Subalpine Areas. In Revegetation of High-Altitude Disturbed Lands, Environmental Resources Center, Information Series No.10, Colorado State University, Ft. Collins, Colorado, July 1974. pp. 31-35.

Berg, W.A., E.M. Barron and L.A. Rhodes. Plant Growth on Acid Molybdenum Mill Tailings as Influenced by Liming, Leaching and Fertility Treatments. pp.207-222 in The Ecology of Resource Degradation and Renewal. M. Chadwick and G. Goodman, eds., Blackwell Sci. Pubs., Oxford (1975).

Berg, W.A. and W.G. Vogel. Toxicity of Acid Coal-Mine Spoils to Plants. in Ecology and Reclamation of Devastated Land, Vol.1, R.J. Hutnik and G. Davis, Eds., Gordon and Breach, New York (1973). pp. 57-68.

Berghoffen, G.S. A Digest: Strip Mine Reclamation. USDA Forest Service (Eastern Regional). Revised Ed., 1964.

Berry, Charles. Personal Communication. Forestry Sciences Laboratory. USDA Forest Serv., Athens, Ga. 1975.

Beverly, R. G. Reclamation of Mine and Mill Wastes. In Proceedings of the Second Mineral Waste Symposium. U.S. Bureau of Mines and IIT Research Institute. Chicago, Ill. March 18-19, 1970, pp. 221-224.

Beverly, R.G., Wastes Management in Mining and Milling of Uranium. Presentation at the International Symposium on Radiation Protection in Mining and Milling of Uranium and Thorium, Bordeaux, France, 9-11 Sept., 1974, Union Carbide Corp., Grand Junction, Colorado.

Bidwell, R.G.S. Physiological Factors in Plant Distribution. In: Plant Physiology. New York. MacMillan Pub. Co., 1974. p. 577-593.

Black, A.L. and F.H. Siddoway. Tall Wheatgrass Barriers for Soil Erosion Control and Water Conservation. J. Soil and Water Conservation. May-June, 1971. p. 107.

Blake, Carl T., W.W. Woodhouse, Jr., E.D. Seneca, and S.W. Broome. Vegetative Dune Stabilization in North Carolina. Agronomy Information Leaflet. The North Carolina Agricultural Extension Service. December, 1973.

Blaser, R.E., H.D. Perry and D.L. Wright. Establishing Persistent Vegetation for Erosion Control on Disturbed Areas during Highway Construction in the Virginias. Presented at the 1975 Annual Meeting, American Society of Agronomy with Southern Association of Agricultural Scientists. New Orleans, La. Feb. 2-5, 1975.

Bloch, Mary Belle, and Paul D. Kilburn. Processed Shale Revegetation Studies, 1965-1973, Colony Development Operation, December, 1973.

Boscak, Vladimir and Jan Tandon. Suppression of Coal Dust Dispersion from Storage Piles. Industrial Hygiene News Report V.17, 4, April, 1974.

Boyce, S.G. and R.W. Merz. Tree Species Recommended for Strip Mine Plantations in Western Kentucky. U.S. Forest Service, Central States Forest Expt Sta. Tech Paper 1960 (1959).

Boyce, S.G. and D.J. Neebe. Trees for Planting on Strip-Mined Land in Illinois. Central States Forest Exp Stat. Tech Paper 164, 1959.

Bradshaw, A.D., T.S. McNeilly, and R.P.G. Gregory. Industrialization, Evolution and the Development of Heavy Metal Tolerance in Plants. In: *Ecology and the Industrial Society*, Brit. Ecol. Soc. Symp. 5:327-343, 1965.

Bradshaw, A.D. Plants and Industrial Waste. Trans. Bot. Soc. Edinb. 41, pp. 71-84 (1970).

Brady, Nyle C. The Nature and Properties of Soils. 8th ed. New York. MacMillan Co., 1974. 639 p.

Bramble, W.C. Reforestation of Strip-Mined Bituminous Soil in Pennsylvania, J. Forestry, 50, 308-314 (1952).

Bramble, W.C. and R.H. Ashley, Natural Revegetation of Spoil Banks in Central Pennsylvania, Ecology 36, 417-423 (1955).

Breeding, C.H. J. Crownvetch as an Aid to Strip Mine Reclamation. Mining Congress J. 47(4), 70 (1961).

Broadfoot, W.M. Problems in Relating Soil to Site Index for Southern Hardwoods. Forest Science 15 (4):354-364, 1969.

Brochard, E. Strip Revegetation. Coal Age 67(3), 64 (1962).

Brown, J.A., Cultural Practices for Revegetation of High-Altitude Disturbed Lands, in Revegetation of High-Altitude Disturbed Lands, Environmental Resources Center, Information Series No. 10, Colorado State University, Ft. Collins, Colorado, July 1974, pp. 59-63.

Brown, James H. Site Factors and Seeding Methods Affecting Germination and Survival of Tree Species Direct Seeded in Surface-Mined Areas. West Virginia Univ. Agricultural Experiment Station. Bulletin 620. March 1973.

Brown, James H. Height Growth Prediction for Black Locust on Surface-Mined Areas in West Virginia. West Virginia Univ. Agricultural Experiment Station. Bulletin 617. February, 1973.

Brown, James H. and E.H. Tryon. Establishment of Seeded Black Locust on Spoil Banks. West Virginia Univ. Agricultural Experiment Station. Bulletin 440. January, 1960.

Brown, James H. Use of Trees for Revegetation of Surface-Mined Areas. Proceedings of the Revegetation and Economic Use of Surface-Mined Land and Mine-Refuse Symposium. Pipestem State Park, W.Va. December 2-4. 1971. pp. 26-28.

Brown, James H. Success of Tree Planting on Strip-Mined Areas in West Virginia. West Virginia Univ. Agricultural Experiment Station Bulletin 473. April, 1962.

Brown, R.L. and A.L. Hafenrichter. Factors Influencing the Production and Use of Beachgrass and Dune Grass Clones for Erosion Control III. Agronomy J. 40, 677 (1948).

Brundage, R. Scott, Depth of Soil Covering Refuse (Gob) vs. Quality of Vegetation, in Proceedings of the First Symposium on Mine and Preparation Plant Refuse Disposal, National Coal Association, Louisville, Kentucky, Oct. 22-24, 1974, pp.183-185.

Buchholz, James. Some Effects of Fertilization on Revegetation of Coal Mine Spoils in Southeastern Montana. M.S. Thesis. Montana State Univ. 1972.

Busch, Richard, Ronald Backer and Lynn Atkins. Physical Property Data on Coal Waste Embankment Materials. Bureau of Mines, RI 7964. Summarized in Dept of the Interior News Release. Feb. 24, 1975. Cole 343-3583.

Byrnes, W.R. and J.H. Miller. Natural Revegetation and Cost Overburden Properties of Surface-mined Coal Lands in Southern Illinois. In: Ecology and Reclamation of Devastated Land. R.J. Hutnik and Grant Davis (eds.). New York. Gordon and Breach, Inc. 1973. p.285-305.

Capp, John P. and Donald W. Gillmore. Fly Ash from Coal Burning Powerplant: An Aid in Revegetating Coal Mine Refuse and Spoil Banks. Presented at the Coal and Environment Technical Conference. National Coal Association. Louisville, Kentucky. Oct. 1974, pp.1-12.

Capp, John P. and John D. Spencer. Fly Ash Utilization. A Summary of Applications and Technology. Bureau of Mines, IC 8433. 1970.

Capp, John P. and Lester M. Adams, Reclamation of Coal Mine Wastes and Strip Spoil with Fly Ash, Proceedings of the Revegetation and Economic Use of Surface-Mined Land and Mine Refuse, Pipestream State Park, W. Va., Dec. 2-4, 1971.

Carroll, Dorothy. Rock Weathering. New York. Plenum Press. 1970. p.203.

Carter, R.P., R.E. Zimmerman, A.S. Kennedy. Strip Mine Reclamation in Illinois. Argonne National Laboratory. Argonne, Ill. December, 1973, No. 31-109-38-2687.

Carter, Ralph P., et. al. Surfaced Mined Land in the Midwest: A Regional Perspective for Reclamation Planning. Argonne National Laboratory. Argonne, Ill. June, 1974. Bureau of Mines Contract No. 0133127.

Chan, F.J. Direct Seeding-From Experimentation to Application. In Erosion Control Symposium Proceedings. U.S. Dept. Agriculture, Soil Conservation Service and Cooperative Extension Service, University of California. Sacramento, Calif., June 11-12, 1974.

Chapman, A.G. Effects of Spoil Grading on Tree Growth. Mining Congress Journal, 53(8), 93 (1967).

Chapman, A.G. How Strip-Land Grading Affects Tree Survival and Growth. South. Ill. Univ. School Agri. Publ. 29, 1967.

Chapman, A.G., Forest Planting on Strip-Mined Coal Lands with Special Reference to Ohio, USDA Forest Serv. Central States Forest Experiment Station, Technical Paper No. 104, December 1944.

Chem-Jet Dust Suppression System. Johnson-March Dust Control Engineers, 3018 Market St., Philadelphia, Pa. 19104.

Chem-Jet. The Practical and Economical Aspects of the Modern Chem Jet Dust Suppression System. Johnson-March Corp. Information Leaflet 1963.

Chemical Treatment of Waste Tailings Puts An End to Dust Storms. E/MJ-April 1974.

Chenck, D. The Promotion of a Vegetative Cover on Mine Slimes, Dams and Sand Dumps. J. South Afr. Inst. of Mining and Metallurgy 60, 525 (1960).

Cheng, Lung. Formation of Airborne-Respirable Dust at Belt Conveyor Transfer Points. Am. Ind. Hygiene Assoc. J. 34, 12 (1973).

Chepil, W.S. Sedimentary Characteristics of Dust Storms: I Sorting of Wind-Eroded Soil Material. American Journal of Science, Vol. 255, January 1957, p. 12-22.

Chepil, W.S. Sedimentary Characteristics of Dust Storms: II Visibility and Dust Concentrations. American Journal of Science, Vol.225, February 1957, p. 104-114.

Chepil, W.S. Sedimentary Characteristics of Dust Storms: III Composition of Suspended Dust. American Journal of Science, Vol.255, March 1957, p.206-213.

Chittenden, Fred J. (ed.) The Royal Horticultural Society Dictionary of Gardening a Practical and Scientific Encyclopedia of Horticulture. III. The Clarendon Press, Oxford, 1956.

Clark, Don A. and James E. Moyer. An Evaluation of Tailings Ponds Sealants. EPA Project No.21 AGR-16. Program Element 1BB040. EPA-660/2 74-965. June, 1974.

Clark, F.B. Forest Planting on Strip-Mined Bituminous Soil in Pennsylvania. Forestry, 50, 308-314 (1952).

Coal Age. Seeding From the Sky. p.84, November, 1968.

Coalgate, Jerry L., David J. Akers and Russell W. Frum. Gob Pile Stabilization, Reclamation and Utilization. Office of Coal Research. PB-224561. May, 1973.

Coal Mine Spoil Reclamation Symposium, Proceedings. October 11-14, 1965, Pennsylvania State University.

Coherex Manual for Dust Control. GB-7 5m April 1070, Witco Chemical Co., Golden Bear Division, P.O. Box 378, Bakersfield, Calif. 93302.

Collings, R.K., A.A. Winer, D.G. Feasby and N.G. Zoldners. Mineral Waste Utilization Studies. pp.2-12 in Proceedings of the Fourth Mineral Waste Utilization Symposium, E.Aleshin, ed., 1974, Illinois Institute of Technology and Research Institute, P.O. Box 4963, Chicago, Ill. 60680.

Control Dust Emissions at Cement Factory. Chemical Engineer. 3/73. p.124.

Cook, C. Wayne. Surface Rehabilitation of Land Disturbances Resulting from Oil Shale Development. Colorado State University, Environmental Resources Center. Information Series No.11. Fort Collins, Colorado, June 1974.

Cook, C. Wayne, Robert M. Hyde, and Phillip L. Sims. Revegetation Guidelines for Surface Mined Areas. Science Series No.16, Col. State Univ. Dec. 1974, 70 pp.

Corner, J.T. Waste Tip Stabilization in the Ruhr. Colliery Guardian. March 1968.

Cornwell, S.M. and E.L. Stone. Nature (London) 217 (5130): 768-769, 1968.

Cornwell, S.M. and E.L. Stone. Availability of Nitrogen to Plants in Acid Coal Mine Spoils. Nature 217, 768 (1968).

Cowherd, Jr. Chatten, Kenneth Axetell, Jr., Christine M. Guenther, and George A. Jutze. Development of Emission Factors for Fugitive Dust Sources, Midwest Research Institute. Prepared for EPA, Contract No. 68-02-0619, EPA-450/3 74-037. June 1974.

Craig, Robert M. Personal Communication to Dr. Richard M. Felder, July 14, 1975.

Cresswell, C.F. Changes in Vegetational Composition, Nutritional Status, Soils, and Microbial Populations with the Establishment of Vegetation in Gold-Mine Dumps on the Witwatersrand. In Ecology and Reclamation of Devastated Land, Vol.2, R.J. Hutnik and G. Davis, Eds., Gordon and Breach, New York (1973). pp. 335-359.

Critical Area Planting. Technical Guide 342, Section IV, U.S. Dept. Agr. Soil Conservation Service, North Carolina, January, 1971.

Crowl, John M. Reclamation of Lands Stripped by the Opencut Method of Coal Production. World Forestry Congress, Vol. 1, 1962. p. 611.

Cummings, W.H. Fertilizer Trials for Improved Establishment of Shortleaf Pine, White Ash and Yellow-Poplar Plantings on Adverse Sites. J. Forestry 39, 942 (1941).

Cummins, David G., William T. Plass and Claude E. Gentry. Properties and Plantability of East Kentucky Spoil Banks. Coal Age. November, 1966. p. 82.

Currier, W.F. and Daniel L.Merkel. Proceedings Critical Area Stabilization Workshop, Report 7A, Agriculture Research Service, USDA, Las Cruces, New Mexico, June 1971, 197 pp.

Curry, J.A. Strip Mining. Carolina Tips. Carolina Biological Supply Co., Burlington, N.C. Vol.29, No.10 (1966).

Czapowskyj, Miroslaw M. Performance of Red Pine and Japanese Larch Planted on Anthracite Coal-Breaker Refuse. In Ecology and Reclamation of Devastated Land, Vol.2, R.J. Hutnik and G. Davis, Eds. Gordon and Breach, New York (1973). pp. 237-245.

Czapowskyj, Miroslaw M. Experimental Planting of 14 Tree Species on Pennsylvania's Anthracite Strip-Mine Spoils. U.S. Forest Service Research Note NE-155 (1970).

Czapowskyj, Miroslaw M. and William E. McQuilkin. Survival and Early Growth of Planted Forest Trees on Strip-Mine Spoils in the Anthracite Region. U.S. Forest Service Research Note NE-46 (1966). pp. 1-29.

Czapowskyj, Miroslaw M., John P. Mikulecky and Edward A. Sowa. Response of Crownvetch Planted on Anthracite Breaker Refuse. USDA Forest Service Research Note NE-78 (1968). pp. 1-6.

Czapowskyj, Mirowslaw M., and Ross Writer. Hydroseeding in Anthracite Coal Mine Spoils. USDA Forest Service Research Note NE-124 (1970).

Dale, J., A.L. McComb, and W.E. Loomis. Chlorosis, Mycorrhizae and the Growth of Pines on a High-Lime Soil. Forest Science 1(2): 148-157.

Dale, Martin E. Interplant Alder to Increase Growth in Strip-Mine Plantations. U.S. Forest Service Research Note CS-14. October 1963. pp.1-4.

Dalrymple, R.L. Weeping Lovegrass Management. Noble Foundation, Ardmore, Oklahoma, 39 pp.

Darimer, G. Grasses and Herbs for Revegetating Phytotoxic Material. In Ecology and Reclamation of Devastated Land, Vol.2, R.J. Hutnik and G. Davis, Eds., Gordon and Breach, New York (1973). pp. 91-101.

Darmer, G. and H.J. Bauer. Landschaft und Tagebau. Grundlagen und Leitsatz für die landschaftspflegerische Neugestaltung einer okologisch ausgewogenen rekultivierten Kulturlandschaft im Rheinischen Braunkohlenrevier. Neve Landschaft, 11/12 (1969).

Daubenmire, Rexford F. Plants and Environment. 3rd ed. New York: John Wiley and Sons. 1974. pp. 422.

Davidson, Walter H. Reclaiming Refuse Banks from Underground Bituminous Mines in Pennsylvania. In Proceedings of the First Symposium on Mine and Preparation Plant Refuse Disposal, National Coal Association, Louisville, Kentucky, Oct. 22-24, 1974, pp. 186-200.

Davis, Grant. Comparison of Fall and Spring Planting on Strip-Mine Spoils in the Bituminous Region of Pennsylvania. In Ecology and Reclamation of Devastated Land, Vol.1, R.J. Hutnik and G. Davis, Eds., Gordon and Breach, New York (1973). pp.525-538.

Davis, Grant. Second-Year Results of Hybrid Poplar Test Plantings on Bituminous Strip-Mine Spoils in Pennsylvania. U.S. Forest Service Research Note NE-19 (1964). pp.1-7.

Davis, Grant and Rex E. Melton. Trees for Graded Strip-Mine Spoils. Pennsylvania State Forest School Research Paper No.32, Feburary 15, 1963, 4 pp.

Davis, John H. Dune Formation and Stabilization of Vegetation and Planting. Tech Memo No.101, Dept. of the Army, Corps of Engineers, 1960.

Day, A.D. and K.L. Ludeke. Stabilizing Copper Mine Tailing Disposal Berms with Giant Bermudagrass. J. Environ. Qualit., 2(2), 314 (1973). pp.314-315.

Dean, K.C. and R. Havens. Methods and Costs for Stabilizing Tailings Ponds. Presentation at the American Mining Congress Mining Convention/Environment Show, Denver, Colo., Sept. 9-12, 1973.

Dean, K.C. and R. Havens. Stabilization of Problem Mineral Wastes. Presented at the Fall Meeting of the Society of Mining Engineers of AIME, Birmingham, Ala., Oct. 18-20, 1972.

Dean, K.C. and R. Havens. Stabilizing Mineral Wastes. Engineering and Mineral Journal, 172, 4, Apr., 1971. pp. 99-103.

Dean, K.C., R. Havens, and M.W. Glantz. Methods and Costs for Stabilizing Fine-Sized Mineral Wastes. U.S. Dept. of Interior. Bureau of Mines RI 7896 (1974) pp.1-26.

Dean, K.C., R. Havens, and K.T. Harper. Chemical and Vegetative Stabilization of a Nevada Copper Prophyry Mill Tailing. U.S. Dept. of the Interior. Bureau of MInes, RI 7261, May 1969, pp. 1-13.

Dean, K.C., R. Havens, K.T. Harper and J.B. Rosenbaum. Vegetative Stabilization of Mill Mineral Wastes. Proceedings of the Symposium on Ecology and Revegetation of Drastically Disturbed Sites. Aug. 5, 1969. pp.119-136.

Dean, K.C., R. Havens and E.G. Valdez. Stabilization of Mineral Wastes. Industrial Water Engineering. 1969. October, pp.30-33.

Dean, K.C., R. Havens, E.G. Valdez. USBM Finds Many Routes to Stabilizing Mineral Wastes. Society of Mining Engineering. December, 1971. Taken from SME Preprint 70-B-342.

Dean, K.C. and G.M. Potter. Use of Polymers for Stabilizing Mineral Wastes. Industrial, Agricultural, Domestic. Ed. by T.F. Yen. Ann Arbor Science Publishers, Inc. Ann Arbor, Mich. 1974.

Deitschmann, G.H. Seedling Survival and Height Growth on Graded and Ungraded Strip-Mined Land in Southern Illinois, USDA Forest Ser. Central States For. Exp. Sta. Note 62 (1950).

Deitschmann, G.H. and R.D. Lane, Forest Planting Possibilities on Indiana Coal-Stripped Lands, USDA For. Ser., Cent. States For. Expt. Sta. Tech. Paper 131 (1952).

DenUyl, Daniel. Survival and Growth of Hardwood Plantations on Strip Mine Spoil Banks of Indiana. J. Forestry, 60, 603 (1962).

DenUyl, Daniel. Trees for Reforestation in Indiana. Purdue University, Agriculture Expt. Sta. Circular No.306, Lafayette, Ind.

Design Guidelines for Dust Control at Mine Shafts and Surface Operations, 2nd Ed., Mining Association of Canada. Toronto, 1974.

Despard, Thomas L. Avoid Problem Spoils through Overburden Analysis. USDA For. Ser. Gen. Tech. Report NE-10, N.E. For. Exp. Sta., 6816 Market St., Upper Darby, Pa. 19802. 4 p., 1974.

Development of Source Assessment Documents. Contract 68-02-1329, Task 14. Monsanto Research Corp. June 21, 1974.

Dickens, Ray and Orr, H.P. Roadside Revegetation and Erosion Control. State of Alabama Highway Department. Bureau of Research and Development. HPR Report No.44. March 1969. 233 pp.

Dickerson, J.A. The Effect of Irrigation with Municipal Sewage Effluent and Sludge on Selected Trees, Grasses and Legumes Planted in Bituminous Strip-Mine Spoil. M.S. Thesis. The Pennsylvania State University, University Park, Pa.

Dickinson, S. Revegetation of Taconite Tailing. 1975 Proceedings of the Solid Mineral Waste Stabilization Liason Committee, Vail, Colo., Aug. 7-8, 1975.

Down, C.G. Life Form Succession in Plant Communities on Colliery Waste Tips. Environ. Pollut., 5, 19 (1973).

Dust Control at Ohio Valley. Mining Congr. Jl. 57(11), 88 (1971).

Dust Suppression-How to Control Stockpile and Materials Handling Dust Emission. Rock Products, May 1972, pp.137ff.

Eaman, Tom. Plant Species Potentials for High-Altitude Revegetation, in Revegetation of High-Altitude Disturbed Lands, Environmental Resources Center, Information Series No.10. Colorado State Univ., Ft. Collins, Col., July 1974, pp.39-43.

Eaton, F.M. Deficiency, Toxicity, and Accumulation of Boron in Plants. J. Agr. Research 69, 237 (1944).

Echols, James W. and R.L. Cuany. Seed Supplies and Plant Materials Work Group Summary, in Revegetation of High-Altitude Disturbed Lands, Environmental Resources Center, Information Series No.10, Colorado State Univ., Ft. Collins, Col., July 1974, pp.83-87.

Ehrle, Elwood B. Pioneer Shale Bank Communities. Castanea, 25, No.2, (1960). pp. 80-83.

Einarsson, Eythor. Invasion of Terrestrial Plants on the New Volcanic Island Surtsey. In: Ecology and Reclamation of Devastated Land, R.J. Hutnik and Grant Davis (eds.). New York Gordon and Breach, Inc., 1973. p.253-270.

Einspahr, D.W., A.L. McComb, F.F. Riechen and W.D. Shrader. Coal Spoil-Bank Materials as a Medium of Plant Growth. Proc. Iowa Acad. Sci. 62, 329-344 (1955).

Erbisch, Frederic H. Laboratory Study of Two Grasses Grown on Copper Tailings Supplemented on Aluminum Alum. The Michigan Botanist 13, 3-9 (1974).

Erbisch, Frederic H. Private communication to Mr. R.P. Donovan. June 9, 1975.

Eschner, Arthur R. Observations on a Hybrid Poplar Test Planting in W. Va. U.S. Forest Service. Northeastern Forest Expt. Sta. Research Note 111, (1960.)

Eyre, S.R. Vegetation and Soils. Chicago, Ill. Aldine Pub. Co. 1968. 328 p.

Farmer, Eugene, Ray W. Brown, B.Z. Richardson and P.E. Packer. Revegetation Research in the Decker Coal Mine in Southeastern Montana. USDA Forest Serv. Res. Paper INT-162, 1974, 12 pp.

Finn, R.F. Foliar Nitrogen and Growth of Certain Mixed and Pure Forest Plantings. J. Forestry 51, 31 (1953).

Finn, R.F. Ten Years of Strip-Mine Forestation Research in Ohio. U.S. Forest Serv. Central States Forest Expt. Sta. Tech Paper 153 (1958).

First Weeping Lovegrass Symposium Proceedings. Samuel Roberts Nobel Foundation, 1970.

Fleming, A.L., J.W. Schwartz and C.D. Foy. Chemical Factors Controlling the Adaptation of Weeping Lovegrass and Tall Fescue to Acid Mine Spoils. Agronomy Journal, 66, 715 (1974). pp.715-719.

Flexibility Enhances Results in Two-Seam Surface Mining. Coal Age. Jan. 1966. p.61.

Flexible Mountaintop Surface Mining. Coal Age. April 1964. p.118.

Florida Phosphate Slimes Problem. U.S. Dept. of Interior, Bureau of Mines Information Circular 8668 (1975), 41 pp.

Foth, H.D. and L.M. Turk. Fundamentals of Soil Science, 5th ed. New York. John Wiley and Sons, Inc. 1972. 454 p.

Fowells, H.A. Silvies of Forest Trees of the United States. U.S. Dept. of Agriculture, Agriculture Handbook No.271, 1965, 762 pp.

Francis, James M. Mine-Waste Reclamation via Vegetative Stabilization. Presented at the Annual Convention of the American Society of Agronomy, Kansas City, Missouri, November 16, 1974.

Francis, James M. Vegetative Stabilization of Mine Waste. Presented at the Coal Mine Spoil Reclamation Symposium, Pennsylvania State Univ., Oct. 14, 1965.

Francis, James M. Stabilizing Iron-ore Tailings with Vegetation, in Ecology and Reclamation of Devastated Land, Vol.2, R.J. Hutnik and G. Davis, Eds., Gordon and Breach, New York (1973). pp.451-455.

Frank, Robert M. A Guide for Screen and Cover Planting of Trees on Anthracite Mine-Spoil Areas. U.S. Forest Serv. Res. Note NE-22 (1964). p.30.

Frawley, M.L. Surface-Mined Areas: Control and Reclamation of Environmental Damage-A Bibliography. U.S. Dept. Interior, Office of Library Sciences, Biblio. Series No.27, 1971, 63 pp.

Frost, J.F. and H.L. Piper. Stabilization of Tailings Pile No.2 at the Rifle Mill West of Rifle, Colorado: Union Carbide Corp., Rifle, Col., Sept. 27, 1968, 3 pp.

Funk, David T. and Martin E. Dale. European Alder: A Promising Tree for Strip-Mine Planting. Central States Forest Experiment Station Note No.151, September 1961, pp.1-2.

Funk, David T. A Revised Bibliography of Strip Mine Reclamation. U.S. Forest Serv. Control States Forest Expt. Sta. Release 35, 1962.

Funk David T. Hybrid Poplars on Ohio Spoil Banks. U.S. Forest Service Research Note CS-8, June 1963, pp.1-4.

Funk, David T. and Rodney R. Krause. Fertilizing Strip-Mine Plantings Benefits Some Hardwoods. USDA Forest Service Tree Planters Notes, 71, 21-22 (1965).

Funk, David T. Growth and Development of Alder Plantings on Ohio Strip-Mine Banks, in Ecology and Reclamation of Devastated Land, Vol.1, R.J. Hutnik and G. Davis, Eds., Gordon and Breach, New York (1973) pp. 483-491.

Gale, J. and R.M. Hagan. Plant Antitranspirants. Annual Reviews of Plant Physiology 17:269-282, 1966.

Gartside, D.W. and T. McNeilly. Genetic Studies in Heavy Metal Tolerant Plants II. Zinc Tolerance in Agrostis Tenus. Heredity, Vol.33, Part 3, pp.303-308, December 1974.

George, Ernest J. 31 Year Results in Growing Shelterbelts on the Northern Great Plains. USDA Circular No. 924, 56 pp. 1953.

Gere, E.R. Minnesota Iron Mining Wastes. pp. 229-231 in Proceedings of the Second Mineral Waste Utilization Symposium. M.A. Schwartz, Chairman. March 1970. Chicago, Ill. IITRI, P.O. Box 4963, Chicago, Ill.

Geyer, Wayne A. Reforesting Kansas Coal Spoils. Agricultural Expt. Stat. Kansas State Univ. Circular 399. December 1971. pp.1-9.

Geyer, Wayne, A. Tree Species Performance on Kansas Coal Spoils, in Ecology and Reclamation of Devastated Land, Vol.2, R.J. Hutnik and G. Davis, eds., Gordon and Breach, New York (1973). pp.81-90.

Geyer, wayne A. and Nelson F. Rogers. Spoils Change and Tree Growth on Coal-Mined Spoils in Kansas. J. Soil and Water Conservation, 27, No.3, 114 (L972). pp. 114-116.

Gifford, G.F., D.D. Dwyer and B.E. Norton. Bibliography of literature Pertinent to Mining Reclamation in Arid and Semi-Arid Environments Utah State University. August 1972, 23 pp.

Goldfinger, Howard M. Once a Sand Dune. Soil Conservation. October 1971. pp. 6061.

Goodman, G.T., C.E.R. Pitcairn, and R.P. Gemmell. Ecological Factors Affecting Growth on Sites Contaminated with Heavy Metals, in Ecology and Reclamation of Devastated Land, Vol.2, R.J. Hutnik and G. Davis, eds., Gordon and Breach, New York (1973), pp. 149-173.

Graetz, Karl E. Seacoast Plants of the Carolinas for Conservation and Beautification. USDA Soil Conservation Serv. Raleigh, N.C. Feb. 1973. 206 pp.

Grandt, Allen F. and Lang, A.L. Reclaiming Illinois Strip Coal Land with Legumes and Grasses. Ill. Agr. Expt. Sta. Bull. 628 (1958).

Grandt, Allen F. Reclamation for Pasture and Agricultural Crops, Proceedings of Coal Mine Spoil Reclamation Symposium, Oct. 11-14, 1965, Pennsylvania State Univ., University Park, Pa., pp. 124-128.

Guernsey, J.L. Reclamation of Indiana's Spoil Banks by Tree Plantings. Ann. Assn. American Geographers, 40, pp. 1-8 (1959).

Guidelines for Reclamation of Surface-Mined Areas in Montana, USDA, Soil Conservation Service, Bozeman, Montana, August 1971.

Guernsey, Walter J. Sericea Lespedeza, Its Use and Management. U.S. Dept. Agr. Farmers Bulletin No. 2245. November, 1970. 29 pp.

Gupta, V.C. Effects of Boron and Lime on Boron Concentration and Growth of Forage Legumes under Greenhouse Conditions. Comm. Soil Sci. and Plant Analysis 3(5), 355 (1972).

Gwynn, R.F. Reclaiming Strip-Mined Land by Establishing Game Management Areas Progress Report, Knife River Coal Mining Co., 1966. 42 pp.

Hagen, L.J. and N.P. Woodruff. Air Pollution From Dust Storms in the Great Plains. Atmospheric Environment, Pergamon Press 1973, Vol.7, pp. 323-332.

Hagen, L.J. E.L. Skidmore and J.D. Dickerson. Designing Narrow Strip Barrier Systems to Control Wind Erosion. J. of Soil and Water Cons. 1972.

Hagen, L.J. and N.P. Woodruff. Particulate Loads Caused by Wind Erosion in the Great Plains.J. Air Pollution Control 25, No.8, Aug. 1975, pp.860-861.

Harbart, H.P. and W. A. Berg. Vegetative Stabilization of Spent Oil Shale. Technical Report No.4. Environmental Resources Center, Colorado State Univ., Ft. Collins, Colorado 80523, December 1974.

Harbaz, Y., L. Shannon and N.H. Tadmor. Effects of a Synthetic Rubber Crust Mulch on the Emergence and Early Growth of Three Grasses on Sand Dunes. Israel J. Agr. Res., 15, 149 (1965).

Hart, George and William R. Byrnes. Trees for Strip-Mined Land. U.S. Forest Service Northeast Forest Experiment Station, Paper 136 (1960).

Hardwood, C.F. and T.P. Blasek. Characterization and Control of Asbestos Emissions from Open Sources. Environmental Protection Agency, EPA-650/2-74-909, September 1974. 196 p.

Hartmann, Hudson T. and Dale E. Kester. Plant Propagation. Englewood Cliffs, New Jersey. Prentice-Hall, 1975.

Hashimoto, N., T. Kojima, M. Ogawa and T. Suzuki. Effect of Alder and Acacia on Devastated Land, in Ecology and Reclamation of Devastated Land, Vol.1, R.J. Hutnik and G. Davis, Eds., Gordon and Breach, New York (1973) pp. 357-367.

Havens, R. and K.C. Dean. Chemical Stabilization of the Uranium Tailings at Tuba City, Arizona. U.S. Dept. of the Interior, Bureau of Mines, 1969.

Hedley, W.H., S.M. Mehta, C.M. Moscowitz, A.D. Snyder, H.H.S. Yu, and D.L. Zanders. Sources and Characterization of Fine Particulate Test Dusts. Monsanto Research Corp., EPA Contract 68-02-1220, Task 8, November 1974.

Herod, Sandy. Corson Leads Way in Air Quality Control. Pit and Quarry, May 1971, p.62.

Hill, R.D. Reclamation and Revegetation of 640 Acres of Surface Mines-Elkins, West Virginia, in Ecology and Reclamation of Devastated Land, Vol.2, R.J. Hutnik and G.Davis, Eds., Gordon and Breach, New York (1973), pp.417-449.

Hill, R.D. Reclamation and Revegetation of Strip-Mined Lands for Pollution and Erosion Control. Am. Soc. Agr. Engrs. Trans., 14(2), 268 (1971).

Hinesley, T.D., R.L. Jones and B. Sosewitz. Use of Waste Treatment Plant Soils for Mined Land Reclamation. Mining Congress Jl., 58(9), 66 (1972).

Hitchcock, A.S. Manual of the Grasses of the United States. U.S. Dept. of Agriculture, Misc. Publication No.200, February 1935.

Hodder, R.L. and B.W. Sindelar. Coal Mine Land Reclamation Research. Mont. Agr. Exp. Sta. Res. Rep. 21, 1972, 29 pp.

Hodgson, D.R. and W.N. Townsend. The Amelioration and Revegetation of Pulverized Fuel Ash, in Ecology and Reclamation of Devastated Land, Vol.2, R.J. Hutnik and G. Davis, Eds., Gordon and Breach, New York (1973), pp.247-271.

Holland, F.R. Wildlife Benefits from Strip-Mine Reclamation. In: Ecology and Reclamation of Devastated Land, R.J. Hutnik and Grant Davis (eds.). New York. Gordon and Breach, Inc. 1973. pp.377-388.

Holz, P. South Africa Gold Mine Waste Dumps Get a Face Lift. Canadian Mining Journal, 1962.

Horn, M.L. and W.W. Ward. The Revegetation of Highly Acid Spoil Banks in the Bituminous Coal Region of Pennsylvania. Pennsylvania State Univ. Special Research Report No. SR-71, 1969.

Howard, R.A. and Proctor, G.R. Vegetation of Bauxite Soils in Jamaica, I, II, Journal Ann Arbor. 38, 1-41, 151-169 (1957).

How Green are Our Valleys. Bethlehem Review. July, 1968. p. 8.

Hudson, N. Soil Conservation. Cornell Univ. Press, 124 Roberts Place, Ithaca, New York 14850 (1971).

Hutcheson, J.R.M. Environmental Control in the Asbestos Industry of Quebec. Can. Mining Bull., 64, No.712, 83-89 (1971).

Hutnik, R.J. and G. Davis (eds.) Ecology and Reclamation of Devastated Land. 2 Volumes. Gordon and Breach, 1973.

International Symposium on Ecology and Revegetation of Drastically Disturbed Areas Proceedings. Pennsylvania State University. University Park, Pennsylvania. 1969.

Inventorying of Emissions from Agricultural Tilling, Unpaved Roads and Airstrips, and Heavy Construction Sites, EPA Contract No. 68-02-1437. November 27, 1974. Midwest Research Institute. Kansas City, Mo.

Jacobson, J.S. and A.C. Hill. Recognition of Air Pollution Injury to Vegetation: A Pictorial Atlas. ittsburg, Pennsylvania, Air Pollution Control Association. 1970.

Jacoby, Jr., Pete W. Revegetation Treatments for Stand Establishment on Coal Spoil Banks. J. Range Management, 22, No.2, 94 (1969).

James, A.L. Stabilizing Mine Dumps with Vegetation. Endeavor, 96 (1966).

Jonas, F. Reclamation of Areas Damaged by Mining Activity in Czechoslovakia, in Ecology and Reclamation of Devastated Land, Vol.2, R.J. Hutnik and G. Davis, Eds., Gordon and Breach, New York (1973) pp.379-393.

Jones, J.N., W.H. Armiger, and O.L. Bennett. A Two-step System for Revegetation of Surface Mine Spoils. J. Environmental Quality 4(2):233-235, 1975.

Jones, W.G. Hybrid Poplar Plantings on Strip-Mine Sites in Pennsylvania. Proceedings of the 20th Northeastern Forest Tree Improvement Conference, pp. 160-168 (1973).

Jones, W.G. The New Forest. Offset Centre, Inc. State College, Pa. 1970.

Katari, V., G. Issacs and T.W. Devitt. Trace Pollutant Emissions from the Processing of Metallic Ores. PEDCo-Environmental Specialists, Inc. EPA Contract 68-02-1321, Task 5. October, 1974. EPA-650/2-74-115.

Katari, V., G. Isaacs, and T.W. Devitt. Trace Pollutant Emissions from the Processing of Non-Metallic Ores, PEDCo Environmental Specialists, Inc. EPA Contract 68-02-1321. November, 1974. EPA-650/274-122.

Kautz, H.M. and W.A. Hayes. Construction Guidelines for Vegetating Waterbed Structures and Disturbed Areas. Soil Cons. Serv., U.S. Dept. Agr. Upper Darby, Pa. 1963.

Kay, B.L. The Role of Erosion-Control Fibers and Chemicals. In: Erosion Control Symposium Proceedings. U.S. Dept. Agriculture. Soil Conservation Service and Cooperative Extension Service. Univ. of Calif. Sacremento, Calif. June 11-12, 1974.

Keen, P.R. Vegetation to Stabilize Mine Dumps. Mining Mag., 1965.

Kenahan, C.B. and E.P. Flint. Bureau of Mines Research Programs on Recycling and Disposal of Mineral-, Metal-, and Energy-Based Solid Wastes, Bureau of Mines, 1971, IC 8529.

Kendig, John D. Hybrid Poplars Renew Mixed Land. Coal Age, 73, 78 (1968).

Kentucky Department of Natural Resources. Surface Mining and Reclamation in Kentucky, 1972. pp. 1-48.

Kirkland, Jr., Gordon, L. Effects of 5-10-5 Fertilizer on the Vegetation of an Open-Pit Mine Waste Disposal Site in Essex County, New York. Proc. Va. Acad. Sci., 48, 137-138 (1974).

Knabe, Wilheml. Development and Application of the DOMSDORF Ameliorative Treatment on Toxic Spoil Banks of Lignite Opencast Mines in Germany, in Ecology and Reclamation of Devastated Land, Vol2, R.H. Hutnik and G. Davis, Eds., Gordon and Breach, New York (1973), pp.273-293.

Knudsen, L.L. and P.H. Struthers. Strip-mine Reclamation Research in Ohio. Oohio Jour. Sci., 53, pp.351-355 (1953).

Kohnke, Helmut. The Reclamation of Coal Mine Spoils. Adv. Agronomy 2, 317 (1950).

Kosowski, Z.V. Control of Mine Drainage from Coal Mine Mineral Wastes. Phase II. Pollution Abatement and Monitoring. U.S. Environmental Protection Agency Report EPA-R2-73-230, May 1973.

Krause, Rodney R. Reclamation Program of Ohio Power Co. Mining Congress Jl., 50(8), 78 (1964).

Krause, Rodney R. Spoil Bank Goes from Waste to Fodder. Coal Mining and Processing, May 1964, pp. 29.

Lane, Richard D. Forest Service Reclamation Research. Mining Congress Jl., 54, 88 (1968).

Langer, G. Particle Deposition and Reentrainment from Coniferous Trees. Kolloid Z. and Z. fur polym. 204 (1/2), 119 (1965).

Latimer, I.S. Why Revegetation? In Proceedings of the Revegetation and Economic Use of Surface-mined Land and Mine Reuse Symposium. West Virginia Univ., Morgantown, W.Va. Pipestem State Park, W. Va. December 2-4, 1971. p.2.

Law, J.P. Agricultural Utilization of Sewage Effluent and Sludge. U.S. Dept. Interior, FWPCA, Wash., D.C. 1968.

Law, S.M. and S.M. Vaccaro. Erosion Evaluation Study. Bureau of Public Roads. PB238875. June 1974.

Leichtman, C.H. Data from 3M Co. on XA 2440. A Water Reactive Liquid Co-sprayed with Water onto the Surface of Dust Particles. August 21, 1974.

Lejcher, R.R. Strip Mine Reclamation Utilizing Treated Municipal Wastes. Proc. Symp. on Watersheds in Transition, June 19-22, 1972. Fort Collins, Colorado, pp. 371-376.

Leroy, Jean Claude and Herman Keller. How to Reclaim Mined Areas. Tailing Ponds and Dumps into Valuable Land. World Mining. May, 1972.

Limstrom, G.A. Forestation of Strip-Mined Land in the Central States. U.S. Forest Service Agr. Handbook No. 166, 1960.

Limstrom, G.A. Revegetation of Ohio's Strip-Mined Land. Ohio Journal of Science, 64(2), 112 (1964).

Limstrom, G.A. Extent, Character and Forestation Possibilities of Land Stripped for Coal in the Central States. USDA Forest Serv., Central States Forest Experiment Station, Technical Paper No. 109, December, 1948.

Limstrom, G.A. Rehabilitation of Lands Stripped for Coal in Ohio. USDA Forest Service, Central States Forest Experiment Station, Technical Paper No.113, December 1949.

Little, S., C.B. Granmer and H.A. Somes. Direct Seeding of Pitch Pine in Southern New Jersey, USDA For. Serv., Northeastern For. Exp. Sta. Paper 111 (1958).

Loomis, T.H.W. Compiled Research Data on Reclamation of Disturbed Lands in the Western United States, Bureau Land Mgmt., 1970. 24 pp.

Lorio, Jr., P.L. and G.E. Gatherum. Growth of Eastern Cottonwood in Relation to Coal-Spoil Characteristics. Iowa State J. Science, 41(1), 41 (1966).

Lorio, Jr., P.L. and G.E. Gatherum. Relationship of Tree Survival and Yield to Coal-Spoil Characteristics. Iowa Agr. and Home Econ. Expt. Sta. Res. Bull. No.535.

Lorio, P.L. Tree Survival and Growth on Iowa Coal-spoil Material. Ph.D. Dissertation. Iowa State Univ., 1962.

Lorio, Jr., P.L. and G.E. Gatherum, and W.D. Shrader. Tree Survival and Growth on Iowa Coal-Spoil Materials. Iowa Agr. and Home Econ. Exp. Sta. Spec. Rpt. 39 (1964).

Lowry, G.I. Conifer Establishment on Coal Spoils as Influenced by Certain Site Factors and Organic Additions at Planting Time. Soil Science Society of American Proceedings, 24(4):316-318, (1960).

Ludeke, K.L. Vegetative Stabilization of Tailing Disposal Berms of Pima Mining Co. Presented at Amer. Mining Congress, San Francisco, Sept. 19, 1972.

Ludeke, K.L. Soil Properties of Materials in Copper Mine Tailing Dikes. Mining Congress Journal, 59, No.8, 30 (1973).

Ludeke, K.L. Vegetative Stabilization of Tailings Disposal Berms. Mining Congress Journal, 59(2), 32 (1973).

Ludeke, K.L. Private communication to Dr. Richard M. Felder, June 9, 1975.

Ludeke, K.L. Experiments in Tailing Slope Stabilization, to be published (1975).

Lujan, Leandro E. Revegetation of Strip-Mined Areas in Southwestern Wyoming. M.S. Thesis. Univ. of Wyoming, 1966.

Luxemburg Information. Seminar. Technical Dust Control for Mining. Oct. 11-13, 1972. Translated from the German.

Lyles, L., D.V. Armrust, J.D. Dickerson and N.P. Woodruff. Spray-on Adhesives for Temporary Wind Erosion Control. J. of Soil and Water Cons. October 1969.

MacCartney, John C. and Ralph H. Whaite. Pennsylvania Anthracite Refuse: A Survey of Solid Waste from Mining and Preparation. U.S. Dept. of the Interior. Bureau of Mines, 1969, IC 8409.

Magnuson, Malcolm O. and K.L. Kimball. Revegetation Studies at Three Strip-Mine Sites in North Central Pennsylvania, National Technical Information Service. U.S. Dept. of the Interior. U.S. Bureau of Mines. February, 1968, 1969. RI 7075.

Marx, Donald. Personal Communication. Forestry Sciences Laboratory. USDA Forest Service. Athens, Ga. 1975.

Mason, B. Principles of Geochemistry, 3rd Ed. John Wiley and Sons, New York, New York (1966).

Massey, H.F. pH and Soluble Cu, Ni and Zn in East Kentucky Coal Mine Spoil Materials. Soil Sci., 114(3), 217-221 (1972).

May, J.T., C.L. Parks and H.F. Perkins. Establishment of Grasses and Tree Vegetation on Spoil from Kaolin Strip Mining, in Ecology and Reclamation of Devastated Land, Vol.2, R.J. Hutnik and G. Davis, Eds., Gordon and Breach, New York (1973). pp.137-147.

May, J.T. Selection and Use of Trees in Reclamation. In Symposium Proceedings: Rehabilitation of Drastically Disturbed Surface Mined Lands. Georgia Surface Mined Lands. Georgia Surface Mined Land Board, Macon, Ga. November 4-5, 1971.

May, Morton, Robert Lang, Leandor Lujan, Peter Jacoby and Wesley Thompson. Reclamation of Strip Mine Spoil Banks in Wyoming. Research Journal 51. Agricultural Experiment Station. Univ. of Wyoming. September, 1971.

May, J.T. Personal Communication. School of Forest Resources, Univ. of Ga., Athens, Ga. 1975.

Mays, D.A. Fertility Needs for Forage and Fruit Production on a Coal Strip Mine in Northeast Alabama. Presented at the 1975 Annual Mtg. American Society of Agronomy with Southern Association of Agricultural Scientists. New Orleans, La. Feb. 2-5, 1975.

McArthur, E. Durant, Bruce C. Givnta and A. Perry Plummer. Shrubs for Restoration of Depleted Ranges and Distrubed Areas. Utah Science, March 1974.

McCart, G.D. et. al. Guidelines for Reclamation and Revegetation, Surface-Mined Coal Areas in S.W. Virginia. Extension Division, Virginia Polytechnic Institute, Blacksburg, 1973, 44 pp.

McComb, A.L. Mychorrhizae and Phosphorus Nutrition on Pine Seedlings in a Prairie Soil Nursery. Iowa State College Agri. Exp. Sta. Res. Bull. 314, p.581-612, 1943.

McCormick, W.T., H.T. Walworth. Suppression of Coal Dust Dispersion from Storage Piles. Industrial Hygiene News Report, Vol.17, April 1974.

McCreery, R.A. Revegetation and Reclamation of High Backslope Cuts. Presented at the 1975 Annual Mtg., American Society of Agronomy with Southern Assoc. of Agricultural Scientists, New Orleans, La., Feb. 2-5, 1975.

McDougall, Eric. The Moisture Belts of North America. Ecology, Vol. VI, No.4, October 1925.

McDougall, W.B. Forests and Soils of Vermillion County, Ill., with special reference to the Striplands, Ecology 6, 327 (1925).

McNay, Lewis M. Surface Mine Reclamation, Moraine State Park, Penn. Bureau of Mines, 1970, IC 8456.

McWilliams, Jesse L. Annual Technical Report-Plant Materials Field Plantings. USDA, Soil Conservation Service, Big Flats, New York, 1971. 10 pp.

McWilliams, Jesse L. Arnot Bristly Locust-A New Plant for Conservation and Beautification in Pennsylvania. U.S. Soil Conservation Service, Harrisburg, Pa., 1970.

McWilliams, Jesse L. Plant Materials Technical Report-Pennsylvania, USDA, Soil Conservation Service, Big Flats, New York, 1970, 14 pp.

Mechthy, E.A. The International System of Units: Physical Constants and Conversion Facotrs. Revised, NASA SP-7012, Scientific and Technical Information Division, Office of Technology Utilization, National Aeronautics and Space Administration, Washington, D.C. (1969).

Medve, Richard J. Volunteer Woody Plants on Reclaimed Bituminous Strip-Mine Spoils. Proc. Pa. Acad. Sci., 48, 93 (1974), pp.93-94.

Medvick, Charles. Selecting Plant Species for Revegetating Surface Coal-Mined Lands in Indiana-A Forty-Year Period. In Ecology and Reclamation of Devastated Land, Vol.2, R.J. Hutnik and G. Davis, eds., Gordon and Breach, New York (1973), pp.65-80.

Medvick, Charles. Why Reforest Surface Mined Areas. Mining Congress Jl., 51, 86 (1965).

Mellinger, Ross H., Frank W. Glover, Jr. and John G. Hall. Results of Revegetation of Strip Mine Spoil by Soil Conservation Districts in West Virginia, W. Virginia Univ. Agr. Expt. Sta. Bulletin 540, Dec. 1966, p. 1-18.

Merkel, Daniel L. and W.F. Currier. Critical Area Stabilization in New Mexico. Report No.7, Agriculture Research Service, USDA, Las Cruces, New Mexico, Jan. 1973, 44 pp.

Merkel, Daniel L., Jesse W. Hale and Phillip L. Sims. Performance of Seeded Grasses in Northwestern Colorado. General Series 926, Colorado State University, July 1973, 13 pp.

Merkel, Daniel L. Internal Report. U.S. Dept. of Agriculture, Soil Conservation Service, Albuquerque, New Mexico, 1974.

Merkel, Daniel L. Revegetation in the Southwest-Its Hazards and Successes. In Proceedings of the Second Research and Applied Technology Symposium on Mined Land Reclamation, Coal and the Environment Technical Conference, National Coal Association, Louisville, Kentucky, Oct. 22-24, 1974, pp. 189-192.

Merz, R.W. and R.F. Finn. Differences in Infiltration Rates on Graded and Ungraded Strip-Mine Lands. Cent. States For. Exp. Sta. Station Note 65, 1951.

Methods and Costs of Coal Refuse Disposal and Reclamation. Bureau of Mines, 1973, PB-226 725, distributed by NTIS, pp. 1-36.

Meyer, L.D., C.B. Johnson and G.R. Foster. Stone and Woodchip Mulches for Erosion Control on Construction Sites. Journal of Soil and Water Conservation.

Meyer, L.D., W.H. Wischmeier and W.H. Daniel. Erosion, Runoff and Revegetation of Denuded Construction Sites. Trans. Am. Soc. Agr. Engs., 14(1), 138 (1971).

Miles, V.C., R.W. Ruble and R.L. Bond. Performance of Plants in Relation to Spoil Classification in Pennsylvania, in Ecology and Reclamation of Devastated Land, Vol.2, R.J. Hutnik and G. Davis, eds., Gordon and Breach, New York (1973), pp.13-31.

Miller, R.H. and R.J. Collins. Waste Materials as Potential Replacements for Highway Aggregates. pp.51-61 in Proceedings of the Fourth Mineral Waste Utilization Symposium, E. Aleshin, ed., 1974, Illinois Institute of Technology and Research Institute, P.O. Box 4963, Chicago, Ill. 60680.

Minnick, L. John. Control of Particulate Emissions from Lime Plants--A Survey Journal of the Air Pollution Control Association, 21, NO.4, pp.195-200 (1971).

Mittelstadt, G.D. and F.T. Davis. Fugitive Dust: Sources and Control. Mineral Industries Bulletin, 16, 6 (1973). pp. 1-10.

Monticello Mill Tailing Erosion Control Project. Grand Junction Office, U.S. Atomic Energy Commission, Report RMO-3005, Dec. 20, 1963 and Supplement, April 20, 1966.

Moorman, M.L., Agrico Chemical Co., Mulberry, Florida 39860. Private communication to R.M. Felder, RTI, July 29, 1975.

Morgan, Jr., Herman and W.L. Parks. Reclamation of Mined Phosphate Land. Tenn. Agr. Exp. Sta. Bull 416, 1967, 37 pp.

Morris, H.D. The Soluble Mn Content of Acid Soils and Its Relation to the Growth and Mn Content of Sweet Clover and Lespedeza. Soil Science Society of American Proceedings, 13, 362 (1948).

Nakamura, H.H., E. Aleshin and M.A. Schwartz. Utilization of Copper, Lead, and Iron Ore Tailings, pp. 139-148 in Proceedings of the Second Mineral Waste Utilization Symposium, M.A. Schwartz, Chairman, March 1970, Chicago, Ill., IITRI, P.O. Box 4963, Chicago, Ill. 60680.

Needleman, S.M. and C.E. Molineux. Earth Science Applied to Military Use of Natural Terrain, AFCRL-69-0364, Aug. 1969, Air Force Cambridge Research Laboratories, L.G. Hanscom Field, Cambridge, Mass. 01730.

Neuberger, H., C.L. Hosler, and W.C. Kocmond. Vegetation as Aerosol Filter. Biometeorology 2(2):693-702, 1967.

Nevens, Thomas D., William J. Culbertson, Jr., and Richard Hollingshead. Disposal and Uses of Oil Shale Ash, Final Report, U.S. Bureau of Mines Project No. SWD-8, April 1970.

Newhard, E.E. Establishment of Cover of Turf on a Mixture of Stone and Quarry Dust. Highway Research Board. Report of Committee on Roadside Development. Pub. 496. pp. 79-80, 1957.

Nielson, Rex F. and H.B. Peterson. Treatment of Mine Tailings to Promote Vegetative Stabilization. Utah State University Agricultural Expt. Station Bulletin 485, June 1972, pp.1-22.

Nielson, Rex F. and H.B. Peterson. Establishing Vegetation on Mine Tailings Waste, in Ecology and Reclamation of Devastated Land, Vol.2, R.J. Hutnik and G.Davis, Eds., Gordon and Breach, New York (1973), pp.103-115.

Odum, Eugene P. The Strategy of Ecosystem Development. Science 164: 262-270, 1969.

Odum, Eugene P. Ecology. New York, Holt, Rinehart, and Winston, 1963. 546 p.

Olschowy, Gerhard. Landscape Planning on an Ecological Basis. In: *Ecology and Reclamation of Devastated Land*, R.H. Hutnik and Grant Davis (eds.). New York, Gordon and Breach, Inc. 1973. pp.477-483.

Onosode, A.T. and J.F. Redhead. The Reclamation of Land Devastated by Tin Mining on the Jos Plateau, Nigeria, in *Ecology and Reclamation of Devastated Land*, Vol.2, R.J. Hutnik and G. Davis, Eds., Gordon and Breach, New York (1973), pp.407-415.

Oosting, H.J. and W.D. Billings. Factors Affecting Vegetational Zonation on Coastal Dunes. *Ecology* 23:131-141, 1942.

Oosting, H.J. The Study of Plant Communities, 2nd Ed., San Francisco, W. H. Greeman and Co., 1956.

Orr, Howard K. Runoff and Erosion Control by Seeded and Native Vegetation on a Forest Burn. USDA Forest Service Research Paper RM-60, Sept., 1970, 12 pp.

Parker, Paul E. Rehabilitation Potentials and Limitations of Surface-Mined Land in the Northern Great Plains. USDA Forest Service General Technical Rept. INT-14, 1974, 44 pp.

Parsons, J.L. and P.H. Struthers. Crownvetch in Ohio is Vigorous Perennial Legume. Ohio Farm and Home Research, November-December, 1962, p.90-91.

Pasquill, F. The Estimation of the Dispersion of Windborne Material. The Meteorological Magazine, Vol.90, No.1,063, February 1961.

Patterson, J.C. and J.P. Capp. Turf Soil Modification with Sintered Fly Ash. Bureau of Mines. May, 1970, RI 7381.

Pearson, R.W. and Fred Adams, eds. Soil Acidity and Liming. Madison, Wisconsin, American Society of Agronomy. 1967, 274 p.

Pearson, Lorentz C. Principles of Agronomy. New York, Reinhold Pub. Corp. 1967, 434 p.

Peters, J. and J. Sciandrone. Stabilization of Sand Dunes at Vandenberg Air Force Base. J Soil Mech. and Foundations Division (Proc. ASCE) *90*, 97 (1964).

Peters, T.H. Using Vegetation to Stabilize Mine Tailings. J. Soil and Water Conservation, *25*(2), 65 (1970).

Peterson, J.R., T.M. McCalla and G.E. Smith. Human and Animal Wastes as Fertilizers. Fertilizer Technology and Use. 2nd Ed., 1971. pp. 557-596.

Peterson, Howard B. and Ralph Monk. Vegetation and Metal Toxicity in Relation to Mine and Mill Wastes. Utah Agr. Expt. Station. Circular 148, September, 1967.

Planting Sites in the Northeast. Station Paper No.157, N.E. For. Exp. Sta. U.S. For. Ser. Upper Darby, Pa. 24 p. 1961.

Plass, William. T. Pine Seedlings Respond to Liming of Acid Strip-Mine Spoil. USDA Forest Service Research Note NE-103 (1969), pp.1-4.

Plass, William T. Tree Survival and Growth in Fescue-Covered Spoil Banks. U.S. Forest Service Research Note NE-90, (1968).

Plass, William T. and James D. Burton. Pulpwood Production Potential on Strip-mined Land in the South. J. Soil and Water Conservation 22, No.6, 235 (1967).

Plucknett, Donald L. Root Growth in Bauxite Soils. Hawaii Farm Science, July 1961, p.8.

Plummer, A. Perry. Oldman Wormwood to Stabilize Disturbed Areas. Utah Science, March 1974.

Plummer, Perry. Personal Communication. Intermountain Forest and Range Experiment Station, Great Basin Experimental Area, Ephraim, Utah. 1975.

Podgorow, N.W. Plantings as Dust Filters. Les. Khoz. 20:39-40, 1967.

Potential Energy Sources Pose Mining Problem. Chemical and Engineering News, April 15, 1974.

Potter H.S., S. Weitzmann and G.R. Trimble, Jr. Reforestation of Strip-Mined Lands in West Virginia. USDA For. Ser. Central States For. Exp. Sta. Paper 43 (1951).

Preston, George T. Application of Engineering Fundamentals to Evaluation of Dust Collection Devices. Garrett Research and Development Co., Inc., LaVerne, California 91750.

Prioritization of Sources of Air Pollution. EPA Contract 68-02-1320, Monsanto Research Corp., July 31, 1974.

Prioritization of Sources of Air Pollution, Impact Factor, Sample Calculations, EPA Contract No. 68-02-1320, August 30, 1974.

Radford, A.E., H.E. Ahles and C.R. Bell. Manual of the Vascular Flora of the Carolinas, University of North Carolina Press, Chapel Hill, North Carolina, 1968.

Rao, D.N. A Study of the Air Pollution Problem Due to Coal Unloading in Varanasi, India. In Proceedings of the Second Clean Air Congress, H.M. Englund and W.T. Beery (eds.). Air Pollution Control Association. Wash., D.C., December 6-11, 1970, pp.273-276.

Reclamation of Strip Mine Spoil Banks in Wyoming. Research Journal 51, Agricultural Experiment Station, Univ. of Wyoming, September 1971.

Reclamation from Coal Mine Waste Dumps. Can. Min. Metal Bull., 65, 83 (1972).

Reed, John B. Phosphate Companies Succeed in Surface-Mined Reclamation. Soil Conservation Magazine, April 1970.

Research Applied Technology Symposium on Mined Land Reclamation. Pittsburgh, Pennsylvania, March 7-8, 1973, National Coal Assn.

Research and Applied Technology Symposium on Mined Land Reclamation Proceedings, Bituminous Coal Research Research Inc., Monroeville, Pa. 1973.

Restriction of Emission Portland-Cement Works. Translated from the German for the National Air Pollution Control Administration, February 1967, VDI-Richtlinien. VDI 2094.

Restriction of Emission Pretreatment and Mixing Plants for Road-Surfacing Aggregates with Bituminous Binder. Translated from the German for the National Air Pollution Control Adminstration, July 1967, VDI-Richtlinien, VDI 2283.

Revegetation and Economic Use of Surface-Mined Land and Mine Refuse Symposium Proceedings, West Virginia University, 1971.

Revegetation. USDA Forest Service, Berea, Ky. 40403, Report ARC-71-66-T4.

Richards, L.A. (ed.) Diagnosis and Improvement of Saline and Alkali Soils. U.S. Dept. Agr. Handbook 60, 160 p. (1954).

Riley, Charles V. Chemical Alterations of Strip-Mine Spoil by Furrow Grading-Revegetation Success, in Ecology and Reclamation of Devastated Land Land, Vol.2, R.J. Hutnik and G. Davis, Eds., Gordon and Breach, New York (1973), pp.315-331.

Riley, Charles, V. Reclamation of Coal Strip-Mined Lands with Reference to Wildlife Plantings. Jl. Wildlife Mgmnt. 21, 402-413 (1957).

Robinson, W.E. and G.L. Cook. Compositional Variations of Organic Material from Green River Oil Shale. U.S. Bu Mines, RI 7820, Laramie Energy Research Ctr., Laramie, Wyo. 1973.

Rock Products. Dust Suppression: How to Control Stockpile and Materials Handling Dust Emission. Rock Products Reference File. May, 1972.

Rogers, Hugo Homer. Uptake of Nitrogen Dioxide by Selected Plant Species. Ph.D. Dissertation. Univ. of North Carolina. Chapel Hill. Dept. of Environmental Sciences and Engineering, 1975.

Role of Plants in Improving the Environment. J. Environ. Quality. 1(2), 123 (1972).

Ruffner, J.D. New Plants for Alleghenies. Strip Mine Spoils and Shale Soils. Soil Conservation, 27(a), 209 (1962).

Ruffner, J.D. and John G. Hall. Crownvetch in W.Va. West Virginia Agr. Expt. Sta. Bull. 487, 1963.

Ruffner, J.D. Adaptation and Performance of Shrubs in Mine Spoil Reclamation. Proceedings of Coal Mine Spoil Reclamation Symposium, Oct. 11-14, 1965. Pennsylvania State University, University Park, Pa. pp.111-116.

Ruffner, J.D. An Evaluation of Species Planted on Coal Strip Mine Spoil in West Virginia for Stabilization Purposes, 1955-1965. Soil Conservation Service. Morgantown, W.Va. (1966).

Ruffner, J.D. and W.W. Steiner. Evaluation of Plants for Use on Critical Sites, in Ecology and Reclamation of Devastated Land, Vol.2, R.H. Hutnik and G. Davis, eds., Gordon and Breach, New York, 1973, pp.3-12.

Salisbury, F.B. and C. Ross. Plant Physiology. Belmont, Calif., Wadsworth, 1969.

Saltsman, R.D., R.D. Harris and K.M. Morse. Survey of Dust Control Research. Bituminous Coal Research, Inc. Prepared for Bureau of Mines. May 1973. PB-222 831.

Salt Marsh Established in Spoil. World Dredging and Marine Construction, 9, 60(1973).

Sand Stabilization. J. Soil and Water Cons. 29(3), 129 (1974).

Sargent, Charles S. Manual of the Trees of North America (Exclusive of Mexico). The Riverside Press, Cambridge, 1933.

Savage, R.P. and W.W. Woodhouse, Jr. Creation and Stabilization of Coastal Barrier Dunes. Proceedings of the 11th Conference on Coastal Engineering. London, England. September, 1968. Published by ASCE, 1969.

Schellie, Kenneth L. and David A. Rogier. Site Utilization and Rehabilitation Practices for Sand and Gravel Operations. National Sand and Gravel Association, 1963, 80 pp.

Schessler, T.E. and Richard F. Droegl. Strip-Mine Reclamation: A Digest. J. Soil and Water Cons. 20, 17-20 (1965).

Schimp, Park E. Deep-mine Waste Reclamation Experimentation in the Bituminous Regions of Pennsylvania, in Ecology and Reclamation of Devastated Land, Vol.2, R.J. Hutnik and G. Davis, Eds., Gordon and Breach, New York (1973), pp.457-467.

Schlatzer, G. Some Experiences with Various Species in Danish Reclamation Work, in Ecology and Reclamation of Devastated Land, Vol.2, R.J. Hutnik and G. Davis, eds., Gordon and Breach, New York (1973), pp.33-64.

Schmehl, W.R. and B.D. McCaslin. Some Properties of Spent Oil-Shale Significant to Plant Growth, in Ecology and Reclamation of Devastated Land, Vol.1, R.J. Hutnik and G. Davis, Eds., Gordon and Breach, New York (1973), pp. 27-43.

Schramm, J.R. Plant Colonization Studies on Black Wastes from Anthracite Mining in Pennsylvania. Trans Am. Phil. Soc., 56, Part I, (1966), pp.1-194.

Schwartz, Murray A. Ed. Proceedings of the Second Mineral Waste Utilization Symposium. Chicago, Ill. March 18-19, 1970.

Schwartz, Murray A. Ed. Proceedings of the Third Mineral Waste Utilization Symposium. Chicago, Ill. March 14-16, 1972.

Searle, S.A. Environment and Plant Life. London, Faber and Faber, (1973), Appendix One.

Seidel, Kenneth W. and Kenneth A. Brinkman. Mixed or Pure Walnut Plantings on Strip-Mined Land in Kansas. Central States Forest Experiment Station. Technical Paper 183, February 1962. pp.1-10.

Sharp, W. Curtis, and Theodore E. Adams, Jr. Erosion Control Symposium Proceedings. USDA, Soil Conservation Service, June 1973.

Sherman, G.D. et. al. Land Reclamation in Hawaii. Crop and Soils, 12(9), 18 (1960).

Shetron, S.G. and R. Duffek. Establishing Vegetation on Iron Mine Tailings. Jl Soil and Water Conservation, 25, pp.227-230 (1970).

Shirts, M.B., W.R. McDonald, M.W. Glantz and G.M. Potter. Progress in Stabilizing Mineral Wastes. In Proceedings of the Fourth Mineral Waste Utilization Symposium. Bureau of Mines and IIT Research Institute. Chicago, Ill., May 7-8, 1974, pp.269-273.

Shirts, Monte B. Private Communication to Dr. R.M. Felder, June 16, 1975.

Sierra Chemical Company, Newark, California.

Sims, P.L. and E.F. Redente. Revegetation of Disturbed Surface Soils in Various Vegetation Ecosystems of the Piceance Basin. Tech. Rprt. No.5. Environmental Resources Centr. Colo. State Univ., Ft. Collins, December 1974.

Sindelar, Brian W., Richard L. Hodder and Mark E. Majerus. Surface Mined Land Reclamation Research in Montana. Research Report 40, Montana Agr. Expt. Station, Montana State Univ., April, 1973, 122 pp.

Sindelar, Brian W., Richard Atkinson, Mark Majerus, and Ken Proctor. Surface Mined Land Reclamation Research at Colstrip, Montana. Research Report 69, Montana Agr. Expt. Station, Montana State Univ., 1974.

Skidmore, E.L. Assessing Wind Erosion Forces: Directions and Relative Magnitudes. Soil Science Soc. of Amer. Proceedings 29, No.5, 1965.

Skidmore, E.L., P.S. Fisher, and N.P. Woodruff. Wind Erosion Equation: Computer Solution and Application. Soil Science Society of Amer. Proceedings, Vol.34, No.6, 1970.

Smith, R.A.H. and Bradshaw, A.D. Reclamation of Toxic Metalliferous Wastes Using Tolerant Populations of Grass. Nature, 227, No.5256, pp.376-377 (1970).

Smith, R.M., P.C. Twiss, R.K. Krauss, and M.J. Brown. Dust Deposition in Relation to Site, Season, and Climatic Variables. Soil Science Socity of Amer. Proc., Vol.34, No.1, 1970, pp.113-117.

Smith, Walter D. Industry Experience in Revegetating with Trees. Proceedings of the Revegetation and Economic Use of Surface-Mined Land and Mine Refuse, Pipestem State Park, West Virginia, Dec. 2-4, 1971.

Sobek, Andrew A. Properties of Barren Mine Spoils that Influence Revegetation. M.S. Thesis, W. Va. University, 1972.

Sopper, William E., John A. Dickerson and Clifford F. Hunt. Revegetation of Strip Mine Spoils Banks through Irrigation with Municipal Sewage Effluent and Sludge. Compost Science, 11, No.6, pp.6-11 (1970).

Sopper, William E. and L.T. Kardos. Municipal Wastewater Aids Revegetation of Strip-Mine Spoil Banks. J. Forestry, 70(10)612 (1972).

Sopper, William E., L.T. Kardos and B.E. Edgerton. Using Sewage Effluent and Liquid Digested Sludge to Establish Grasses and Legumes on Bituminous Strip-Mine Spoils. Dept. of the Interior, PB 232069, March 1974, pp.1-153.

Sopper, William E., L. T. Kardos and L. E. DiLisso. Reclamation of Anthracite Coal Refuse Using Treated Municipal Wastewater and Sludge. Institute for Research on Land and Water Resources, Pennsylvania State Univ., April 1975, 168 pp.

Sorensen, T.A. SAM Reclaims Steel Mill Slag. Pollution Engineering, Jan., 1975.

Sorrell, Shawn T. Establishing Vegetation on Acidic Coal Refuse Materials without use of Topsoil Cover. In Proceeding of the First Symposium on Mine and Preparation Plant Refuse Disposal, National Coal Association, Louisville, Kentucky, October 22-24, 1974, pp.228-236.

Sources of Assistance in Reclaiming Surface-Mined Lands for Outdoor Recreation. U.S. Dept. of the Interior, Wash., D.C. Publication No. 2416-00061, 1972, 72 p.

Specifications Tables for Industrial Wire Cloth, Woven Wire Screens No.74, 1973, W.S. Tyler, Inc., 8200 Tyler Blvd., Mentor, Ohio 44060.

Spicer, T.S. and P.T. Luckie. Operation Anthracite Refuse: Description of a Research Assault on a Billion Ton Solid Waste Disposal Problem in Northeastern Pennsylvania, pp. 195-204 in Proceedings of the Second Mineral Waste Utilization Symposium, M.A. Schwartz, Chairman, IIT Research Institute, 10 W. 35th St., Chicago, Ill. 60616.

Spray System Solves Dust Problems at Arundel Quarries, Pit and Quarry, February 1973.

Springfield, H.W. Germination and Establishment of Fourwing Saltbush in the Southwest. USDA Forest Service Research Paper RM-55, 1970, 48 pp.

Stabilizing Mine Dumps. Mining Magazine, 119, October 1968.

Stallings, J.H. Continuous Plant Cover-the Key to Soil and Water Conservation. Better Crops with Plant Food, 37(1), 13-20 and 44 (1953).

Statnick, Robert M. Measurement of Sulfur Dioxide Particulate, and Trace Elements in Copper Smelter Converter and Roaster/Reverberatory Gas Streams. EPA, Control Systems Laboratory, EPA-650/2-74-111. October 1974.

Steen, Ordell and William A. Berg. Bibliography Pertinent to Disturbance and Rehabilitation of Alpine and Subalpine Lands in the Southern Rocky Mountains, Information Series No.14, Colorado State Univ., February 1975, 104 pp.

Street, H.E. and G.T. Goodman. Revegetation Techniques in the Lower Swansea Valley, Lower Swansea Valley Project, edited by K.J. Hilton, Longmans Green, London (1967).

Striffler, W. David and Robert F. May. Forest Reforestation of Strip-Mined Areas. Proceedings, Society of American Foresters. Detroit, Mich. October 24-28, 1965.

Strip Mining Heals Its Own Scars. Business Week. November 18, 1965. p.141.

Stroh, J.R., A.E. Carleton and W.J. Seamands. Management of Lutana Cicer Milkvetch for Hay, Pasture, Seed and Conservation Uses. Mont. Agr. Exp. Station, Montana State University, Bull. 666, 1972, 17 pp.

Strum, J.W. Naturally Invading Plant Species on Two Upper Freeport Strip-Mine Spoils. M.S. Thesis. West Virginia University, Morgantown, West Virginia. 1973.

Struthers, P.H. Chemical Weathering in Strip-Mine Spoils. Ohio J of Science 65(2), 125 (1964).

Struthers, P.H. Forage Seedings Help Reclaim Acres of Spoil Banks. Ohio Farm and Home Research, 45(1), 12(1960), pp,12-13.

Struthers, P.H. Chemical Weathering of Strip-Mine Spoils. Ohio J of Science 64(2), 125 (1964).

Struthers, P.H. and J.P. Vimmerstedt. Rapid Stripmine Reclamation, Ohio Report, 50(6), 84 (1965).

Sullivan, H.B. From Open Pit Mines to Grass and Pines. Soil Conservation, Sept. 1969, pp. 29-30.

Surface Mining and Mined Land Reclamation: A Selected Bibliography, Old West Regional Commission, Washington, D.C., October 1974.

Surface Mining and Our Environment, U.S. Dept. Interior, 1967.

Sussman, V.H. and J.J. Mulhern. Air Pollution from Coal Refuse Areas. J. Air Poll. Contr. Assn., July 1964.

Sutton, Paul. Reclamation of Toxic Coal Mine Spoilbanks. Ohio Report, 55(5), 99 (1970).

Sutton, Paul Reclamation of Toxic Stripmine Spoilbanks. Ohio Report, 58(1), 18 (1973).

Sutton, Paul and J.P. Vimmerstedt. Treat Stripmine Spoils with Sewage Sludge. Ohio Report, 58 (6), 121 (1973).

Symposium on Rehabilitation of Drastically Disturbed Surface-Mined Lands Proceedings, Georgia Surface Mined Land Use Borad, Macon, Ga., 1971.

Tailings Revegetation at Rio Algom Mine in Canada. Indust. Wastes, 20 16 (1974).

Takahashi, M., J.C. Moomaw and G.D. Sherman. Crop Production Trials on Strip-mined Floor Soil Show Promise. Hawaii Farm Science, July 1961, p.2.

Tandy, C.R.V. Reclamation of Derelict Land at Stoke on Trent. In Proceedings of the Fourth Mineral Waste Utilization Symposium. Bureau of Mines and IIT Research Institute. Chicago, Ill., May 7-8, 1974, pp. 284-293.

They Said It Couldn't be Done. Bethlehem Review. April 1965, p.4.

Thompson, Donald N. and R.J. Hutnik. Environmental Characteristics Affecting Plant Growth on Deep-Mine Coal Refuse Banks. Research Briefs 6, No.2, 22-25 (1972).

Thompson, L.M. and F.R. Troeh. Soils and Soil Fertility, 3rd ed. New York, McGraw-Hill Book Co. 1973. 495 p.

Thompson, K. and M.I. Mech. Integrating Dust Control Equipment into the Manufacturing Process. Proc. Chemical, 19 (4):83-95, April 1975.

Thompson, Welsey W. Cover Establishment on Strip-Mined Area Using Two Rhizamatous Grass Species. M.S. Thesis. Univ. of Wyoming, 1969.

Thor, Eyvind, George Rink and William T. Plass. Breeding Virginia Pine for Better Growth on Acid Spoil. In Proceedings of the Second Research and Applied Technology Symposium on Mined Land Reclamation. Coal and the Environment Technical Conference. National Coal Association. Louisville, Kentucky. October 22-24, 1974.

Thor, Eyvind and James G. Kring. Planting and Seeding of Loblolly Pine on Steep Spoil Banks. J. Forestry, 62, 575 (1964).

Thornburg, Ashley A. Private communication to Dr. Richard M. Felder, June 20, 1975.

Thornthwaite, C. Warren. The Climates of North America According to a New Classification. The Geographical Review. pp. 633-655.

Townsend, C.E. Legume Selection and Breeding Research in Colorado. In Revegetation of High-Altitude Disturbed Lands, Environmental Resources Center, Information Series No.10, Colorado State University, Ft. Collins, Colorado, July 1974, pp. 36-38.

Townsend, W.N. and D.R. Hodgson. Edaphological Problems Associated with Deposits of Pulverized Fuel Ash, pp.45-56, in Ecology and Reclamation of Devastated Land, Vol.1, edited by R.J. Hutnik and G. Davis, Gordon and Breach, Science Publishers, Inc., 1 Park Ave., New York, New York 10016 (1973).

Transit Planting: A Manual. American Horticultural Society, July 1973, distributed by NTIS.

Tree Planting in the Allegheny Section. Station Paper No. 158. N.E. For. Exp. Sta. U.S. For. Ser. Upper Darby, Pa. 18 p. 1961.

Treshow, M. Environment and Plant Response. McGraw Hill Book Co., New York, New York (1970). Chapters 13, 14.

Tresler, Robert L. Personal Communication to Dr. R.M. Felder, June 27, 1975.

Tresler, Robert L. Strip Mine Reclamation in Wyoming. In Proceedings of the Second Research and Applied Technology Symposium on Mined Land Reclamation. Coal and the Environment Technical Conference. National Coal Association. Louisville, Kentucky. October 22-24, 1974.

Trimble, Jr., George R. Hybrid Poplar Grows Poorly on Acid Spoil Banks at High Elevations in West Virginia. U.S. Forest Service Research Note NE-7, 1963 (N.E. Forest Expt. Station) 4 p.

Tryon, E.H., K.L. Carvell and H.P. Berthy. Planting Coniferous Forests in West Virginia. West Virginia University. Agr. Exp. Sta. Circular 109, 50 pp. (1960).

Tryon, E.H. and R.M. Smith. Development of Vegetation on Century-Old Iron-Ore Spoil Banks. West Virginia Agr. Exp. Sta. Bull. 360, 63 pp. 1953.

Use of Polymers for Stabilizing Mineral Wastes. Industrial Agriculture, Domestic, ed. by T.F. Yen, Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, 1974.

Usui, H. and H. Suzuki. Ecological and Revegetational Problems of the Ashio Devastated Area. In Ecology and Reclamation of Devastated Land, Vol.2, R.J. Hutnik and G. Davis, Eds., Gordon and Breach, New York (1973), pp.395-405.

Usutu's Covered Stockpile Combats Pollution, Coal, Cold and Base Minerals of Southern Africa. February 1973, pp.44-45.

Vande Linde, O.V. Vegetation and Techniques Currently used in Revegetation of Surface-Mined Land. In Proceedings of the Revegetation and Economic Use of Surface-mined Land and Mine Reuse Symposium. West Virginia University, Morgantown, W.Va. Pipestem State Park, West Virginia, December 2-4, 1971. pp.21-22.

Van Eimern, J. Windbreaks and Shelterbelts. Tech. Note No.59. World Meteorological Organization, 1964.

Vanicek, Vlastimil. The Soil-protective Role of Specially-shaped Plant Roots. Biol. Conservation, 5(3), 175 (1973).

Van Lear, David H. Effects of Spoil Texture on Growth of Ky-31 Tall Fescue. U.S. Forest Service Res. Note NE-141, 1971, 7 pp.

Van't Woudt, Bessel D. Erosion Control on Strip-Mined Land. Hawaii Farm Science, July 1961, p.10.

Vogel, W.G. Weeping Lovegrass for Vegetating Strip-Mine Spoils in Appalachia. In: Weeping Lovegrass Symposium, Ardmore, Oklahoma, April 28-29, 1970. pp. 152-162.

Vogel, W.G. All Season Seeding of Herbaceous Vegetation for Cover on Appalachian Strip-Mine Spoils. In Proceedings of the Second Research and Applied Technology Symposium on Mined Land Reclamation, Coal and the Environment Technical Conference, National Coal Association, Louisville, Kentucky, October 22-24, 1974, pp. 175-188.

Vogel, W.G. and W.A. Berg. Grasses and Legumes for Cover on Acid Strip-Mine Spoils. J. Soil and Water Conservation, 23, No.3, 89 (1968).

Water Resources Administration. Joint Construction Sediment Control Project. State of Maryland and Burton C. Becker, et. al. EPA Contract 15030 FMZ, Program Element 1B2042, EPA-660/2-73-035, April 1974.

Webb, L.J. Aluminum Accumulation in the Australian-New Guinea Flora, Aust. Journal Bot. 2, 176-196 (1954).

What's Going on in Eastern Kentucky? Bethlehem Review. March, 1970. p.6.

Wheeler, Wilson H. Progress in Reclamation with Forest Trees. Proceedings of Coal Mine Spoil Reclamation Symposium, October 11-14, 1965, Pennsylvania State University, University Park, Pa. pp. 111-116.

Whitt, D.M. Surface-Mined Land. How Much? What Next? Soil Conservation Magazine, January 1968.

Williams, Roy E. and Alfred T. Wallace. The Role of Mine Tailings Ponds in Reducing the Discharge of Heavy Metal Ions to the Environment. I. Text. National Technical Information Service. Dept. of Commerce. Virginia. August 1973.

Williams, Roy E. and Alfred T. Wallace. The Role of Mine Tailings Ponds in Reducing the Discharge of Heavy Metal Ions to the Environment. II. Appendix. Prepared for the Dept. of the Interior. August 9, 1973. Distributed by NTIS, PB-224 731.

Willis, A.J. Introduction to Plant Ecology. London, George Allen and Unwin, Ltd. 1973. 237 p.

Wilker, Carl. Bring Back the Grass. Soil Conservation 72-73. 1972.

Wilson, Carl L. and Walter E. Loomis. Botany, 3rd ed. New York. Holt, Rinehart and Winston, 1962.

Wilson, H.A. Microbiology of the Strip-Mine Spoil. West Virginia Univ. Agricultural Experiment Station Bulletin 506T. May, 1965.

Willson, Horace. Notes from 11/27/73 telephone conversation with Mr. Willson on dust suppression: Detergent and Truck Cost.

Wind-erosion Control Practices Bring Relief to Motorists, Farmers. Soil Conservation Service, September 1969.

Wood, R.F. and J.V. Thirgood. Tree Planting on Colliery Spoil Heaps. Colliery Engineering, 33, 27 (1956).

Woodhouse, Jr., W.W. and R.E. Hanes. Dune Stabilization with Vegetation on the Outer Banks of North Carolina. U.S. Army Coastal Engineering Research Center Technical Memorandum, No. 22, August, 1967. pp. 1-45.

Woodhouse, W.W., E.D. Seneca and A.W. Cooper. Use of Sea Oats for Dune Stabilization in the Southeast. Shore and Beach, October 1968, pp. 1-7.

Woodruff, N.P. and F.H. Siddoway. A Wind Erosion Equation. Soil Science Proceedings, 29, No.5, Sept/Oct 1965, pp. 602-608.

Young, C.A. The Use of Vegetation to Stabilize Mine Tailings Areas at Copper Cliff. Canadian Mining Journal, June 1969, p.43.

Younge, O.R. Fertility Requirements of Bauxite Stripsoil for Crop Production. Hawaii Farm Science, July 1961, p.6.

Younge, O.R. Fertility Requirements of Bauxite Stripsoil for Crop Production. Hawaii Farm Science, July, 1961. p. 6.

Younge, O.R. and Moomaw, J.C. Revegetation of Stripmined Bauxite Lands in Hawaii. Economic Botany, 14, 316 (1960).

Zak, J.M., C.A. Holden, Jr., and W.O. Hill. An Evaluation of Some Grasses and Legumes on Massachusetts Dam Sites. J. Soil and Water Conservation. November - December, 1971. pp. 230-232.

Zak, J.M. and Bredakis, E. Dune Stabilization at Provincetown, Mass. Shore and Beach, 31(2), 1967.

Zarger, T.G., J.A. Curry and J.C. Allen. Seeding of Pine on Coal Spoil Banks in the Tennessee Valley. In Ecology and Reclamation of Devastated Land, Vol.1, R.J. Hutnik and G. Davis, Eds., Gordon and Breach, New York (1973), pp.509-523.

Zarger, T.G., G.W. Bengtson, J.C. Allen and D.A. Mays. Use of Fertilizers to Speed Pine Establishment on Reclaimed Coal-Mine Spoil in Northeastern Alabama: II. Field Experiments. In Ecology and Reclamation of Devastated Land, Vol.2, R.J. Hutnik and G. Davis, Eds., Gordon and Breach, New York (1973), pp.227-236.

9.0 GLOSSARY

Actinomycetes - Filamentous or rod shaped bacteria.

Aforestation - The artificial establishment of forest crops by planting or sowing on land that has not previously, or not recently, grown tree crops.

Alluvial - Describes material such as earth, sand, gravel, or other rock or mineral materials transported by and laid down by flowing water.

Amendment - Any material, such as lime, gypsum, sawdust, or synthetic conditioners, that is worked into the soil to make it more productive.

Amphoteric - Having both acidic and basic properties.

Amphibole - Common rock forming minerals.

Annual - Plants that live only one year.

Berm - A strip of coal left in place temporarily for use in hauling or stripping. A layer of large rock or other relatively heavy stable material placed at the outside bottom of the spoil to help hold the pile in position (a toe wall). Also used similarly, higher in the spoils for the same purpose.

Biennial - Plants that live two years, usually does not show above ground before the second year.

Bone - Carbonaceous shale containing 40-60% noncombustible materials such as clay intermixed with coal.

Breaker Refuse - Slate, bone, or rock as removed by hand or mechanical cleaners in all classes of breakers.

Broadcast - To scatter or sow seeds.

Calcareous - Containing limestone or other forms of bound calcium.

Chlorosis - A diseased condition in green plants marked by yellowing or blanching.

Conifer - Cone-bearing--any of an order of mostly evergreen trees and shrubs.

Cotyledon - The first leaf or one of the first pair or whorl of leaves developed by a seed plant.

Culm - Refuse from coal screening.

Deciduous - Vegetation which sheds leaves or other parts.

Dicotyledon - A plant with two seed leaves.

Direct Seeding - A method of establishing a stand of vegetation by sowing seed on the ground surface.

Edaphic - Resulting from or influenced by the soil rather than the climate.

Effluent - Any water flowing out of the ground or from an enclosure to the surface flow network.

Elluviation - Movement of soil material from one place to another within the soil, in solution or in suspension, when there is an excess of rainfall over evaporation.

Feldspar - Aluminum silicate with either potassium, sodium, calcium or barium.

Forb - Any herb other than grass.

Friable - Easily crumbled or pulverized.

Gall - A swelling of plant tissue usually due to fungi or insect parasites.

Gangue - The worthless rock or vien matter in which valuable minerals occur.

Grass - a monocotyledonous herb with jointed stems, slender sheathing leaves.

Herb - A seed producing plant species that does not develop persistent woody tissue but dies down at the end of a growing season.

Humus - The organic portion of soil resulting from partial decomposition of plant or animal matter.

Hydroseeding - Dissemination of seed hydraulically in a water medium. Mulch, lime, and fertilizer can be incorporated into the sprayed mixture.

Illite - A silicate of potassium, aluminum, iron and magnesium. A general term for the clay-mineral constituent of agrillaceous sediments belonging to the mica group.

Illuviation - Deposition in an underlying layer of soil (soil horizon B) of colloids, soluble salts, and small mineral particles which have been leached out of an overlying soil layer (soil horizon A). The action occurs in humid climates.

Leaching - The removal of materials in solution by the passage of water through soil.

Legume - Any of a large family of dicotyledonous herbs, shrubs and trees having nodules on the roots that contain nitrogen fixing bacteria--e.g., peas, benas, clover.

Lespedeza - Any of a genus of herbaceous or shrubby leguminous plants such as hay.

Loess - Unstratified, usually buff to yellowish brown, loamy soil, generally deposited by wind transport.

LOI - (loss of ignition) The loss in weight which results from heating a sample to a high temperature (after the sample has been dried to a temperature just above the boiling point of water, removing the free moisture).

Minus Mesh, Minus Sieve - The portion of screened sample passing through the sieve of the stated size. -20 + 30 means that portion of the sample that passed through a No. 20 (0.85 mm) sieve but was retained on a No. 30 (0.60 mm) (Figure 4).

Mollisols - The surface layer of permanently frozen ground in which the ice melts during the summer.

Monocotyledon - Any seed plant having an embroyo with a single cotyledon.

Nodulate - Form or a swelling on a leguminous root that contains symbiotic bacteria.

Orstein - Refers to the hard, cemented B horizon of a podozol.

Overburden - The soil or material covering a layer or vein of valuable ore. To surface mine the ore, the overburden must be stripped off and set aside.

Pedalfer - A soil that lacks a hardened layer of accumulated carbonates.

Pedocal - A soil that includes a hardened layer of accumulated carbonates.

Pelletizing - Formed or compacted into pellets--i.e., soil.

Perennial - Plants that live from year to year; includes trees, shrubs and herbs.

Pioneer - A plant capable of establishing itself in a bare area and initiating an ecological cycle.

Plugging - Transplanting of grass and other species in sod by sections.

Plus Mesh, Plus Sieve - The portion of a screened sample retained on the sieve of the stated size.

Polymorphous - Having many parts or members in a whorl.

Pozzolana - Finely divided siliceous or siliceous and aluminous material that reacts chemically with slaked lime at ordinary temperature and in the presence of moisture to form a strong, slow-hardening cement.

Propagation - Any method employed to increase plants--plant breeding, vegetative, etc.

Resinous - Solid or semisolid amorphous fusible, flammable natural organic substances formed in plant secretions--i.e., pine resin.

Rhizome - An elongated, usually horizontal subterranean plant stem that is often thickened by deposits of reserve food material, produces shoots above and roots below and is distinguished from a true root in possessing buds, nodes and usually scalelike leaves.

Scarification - For thick-coated seeds, scratching of the seed coats to ensure germination at the desired time.

Seed - Plant by scattering seeds.

Seedling - Nursery started plants.

Slag - Substance formed in any of several ways because of chemical action and fusion at furnace operating temperatures--by chemical reaction between refractories and fluxing agents such as coal ash, or between two types of refractories.

Slime - Fine particles derived from ore, associated rock, clay, or altered rock, found in old dumps and ore deposits which have been exposed to climatic action.

Slurry - Fine carbonaceous discharge from a colliery washery; any finely divided solid which has settled out as from thickners.

Slurry Pond - Any natural or artificial pond or lagoon for settling and draining the solids from washery slurry.

Spoils - Overburden left behind a strip mining operating.

Swale - a low-lying or depressed and often wet stretch of land.

Talus - A slope or pile of rock debris.

Terete - Of approximately cylindrical shape but usually tapering at both ends.

Talus - A slope or pile of rock debris.

Tailings - The leftover minerals, after the desirable (valuable) ores have been removed; these leftovers are without economic value and are discarded.

Volunteer - Growing spontaneously without direct human control or supervision.

Weathering - The group of processes, such as chemical action of air and rainwater and of plants and bacteria and the mechanical action of changes in temperature,, whereby rocks, on exposure to the weather, change in character, decay, and finally crumble.

Xeric - Requiring only a small amount of moisture.

Xerophilous - Thriving in or tolerant of xeric environment.

10.0 APPENDICES

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APPENDIX A

WOODRUFF WIND EROSION EQUATION

The eleven primary variables of wind erosion (Section 5.1) are not independent. For example, the quantity, kind and orientation of vegetative cover all depend upon plant species. These variables in turn influence soil moisture content, local wind velocity at the ground level, sheltered distance, etc.

One useful combination of meteorological variables is to create a general climatic erosion index from the wind velocity and soil surface moisture variables as follows (Woodruff and Siddoway, 1965; Cowherd, _et al_. 1974):

$$C' = 34.483 \frac{v^3}{(P-E)^2} \qquad (1)$$

where C' = the wind erosion climatic factor [%, relative to climate of Garden City, Kansas]

v = the mean annual wind velocity corrected to a standard height of 9.14 m (30 feet) [mph]*

$P-E$ = the Thornthwaite precipitation/evaporation index (Thornthwaite, 1931) which is a function of soil moisture content (dimensionless)

34.483 = normalizing factor to make $C' = 100$ at Garden City, Kansas, circa 1954-1956 $[\text{mph}]^{-3}$*

The wind erosion climatic factor describes general long term average weather and climatic conditions over which local variations have little or no influence over a long period of time. The wind velocity at 9.14 m (30 feet) is relatively independent of the terrain beneath; the P-E index is a regional measure of precipitation and evaporation (evaporation is calculated from temperature (Thornthwaite, 1931). Maps of both P-E index and the resulting climatic factors C' (eq.1) for the U.S. are shown in Figures 16 and 17 respectively. These factors are assumed to be natural phenomena beyond human control; that is, weather or climatic changes are ruled out as control methods for minimizing wind erosion. At the local level, however, wind velocity and surface moisture levels can be altered greatly; indeed, methods for doing one or the other or both constitute the basis for all the major control methods.

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*SI units are not used here in order to preserve the constants in this equation in their original values.

THORNTHWAITE'S PRECIPITATION - EVAPORATION INDEX

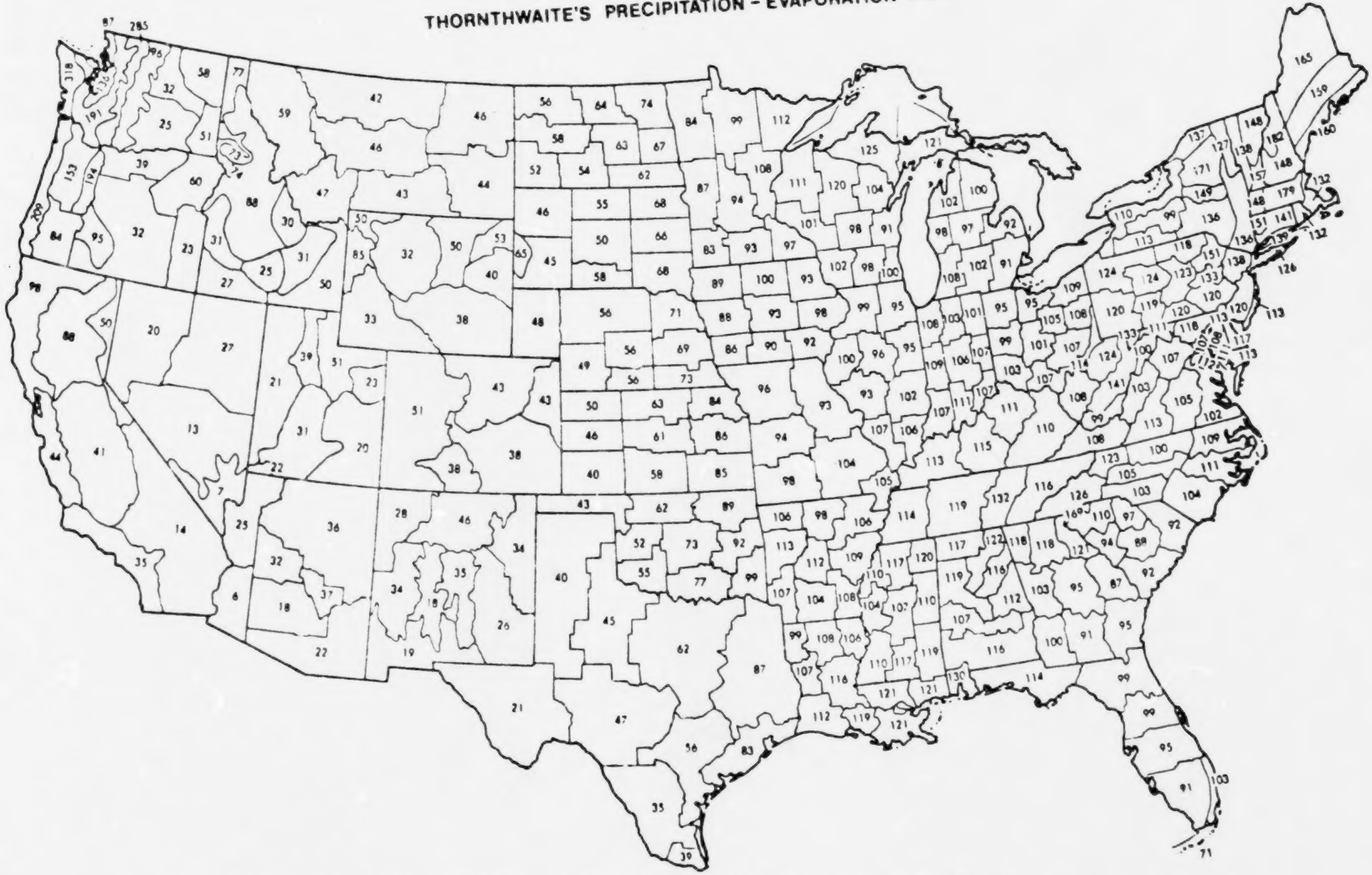
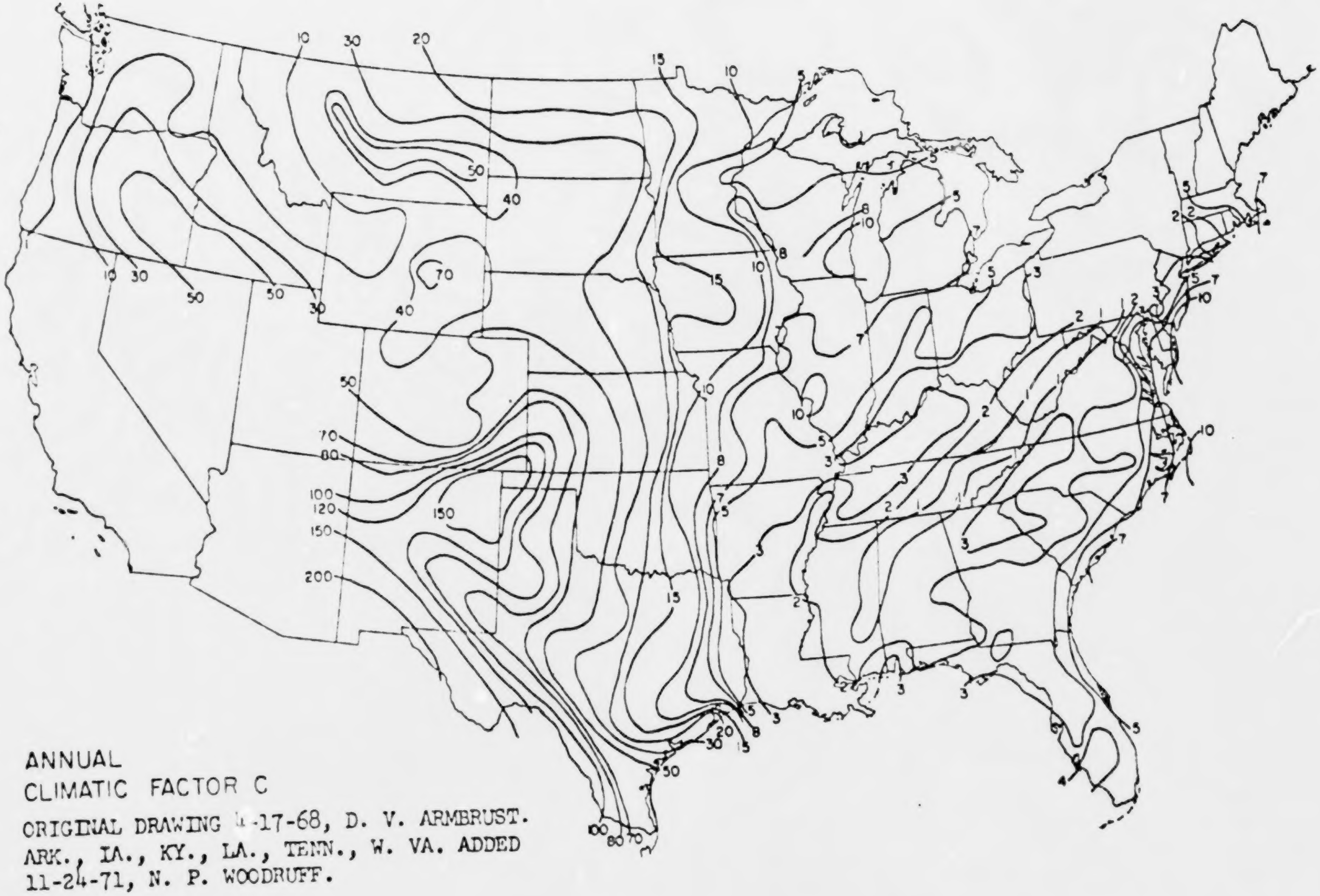


Figure 16. Thornthwaite's Precipitation-Evaporation Index (P-E).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ORIGINAL DRAWING 4-17-68, D. V. ARMBRUST.
ARK., IA., KY., LA., TENN., W. VA. ADDED
11-24-71, N. P. WOODRUFF.

Figure 17. Climatic factor used in wind erosion equation.

The climatic erosion index is but one variable in a general wind erosion equation developed by Woodruff and others (Woodruff and Siddoway, 1969; Skidmore, Fisher and Woodruff, 1970). In this equation the eleven primary variables given in Section 5.1 are reduced to five as follows:

$$E = f(I', K', C', L', V)$$

where E = an erosion rate (soil loss in tons/acre/yr)

I' = a soil erodibility factor

K' = a soil-ridge roughness factor

C' = the climatic factor given in equation 1

L' = the median unsheltered travel distance across a given field

V = an equivalent vegetative cover factor

The five variables of equation 2 represent a regrouping, conversion and combining of the original eleven variables. Forms for facilitating those field measurements needed to calculate E have been published by Skidmore, Fisher and Woodruff (1970) who have also developed a computer program to carry out the calculations.

The Woodruff equation predicts total soil erosion rate--soil movement due to saltation and creep as well as suspension. Consequently it does not predict increases in total suspended particulates. The two quantities are directly, although not simply, related.

APPENDIX B

CATALOG OF PLANTS USED AND/OR RECOMMENDED FOR SPOIL REVEGETATION

This Appendix provides brief descriptions of the plant species referenced in earlier sections of the report, along with summaries of experiences in which the species were included in mineral spoil and tailing revegetation programs. The species are listed alphabetically by common name.

AILANTHUS: *Ailanthus altissima*

Hardwood trees, confined chiefly to the tropics and warmer parts of Northern Hemisphere including the eastern United States (Sargent, 1933). Volunteers on Pennsylvania bituminous spoils (Medve, 1974). Twenty percent survival after 10 years on Indiana spoils (DenUyl, 1962).

ALDER: European Black - *Alnus glutinosa*
Speckled - *A. sucana*

Hardwood trees inhabiting swamps, river bottom-lands and high mountains; widely and generally distributed throughout the Northern Hemisphere (Sargent, 1933).

Planted in Japan to control erosion, to attain rapid covering of denuded land and to promote the growth of conifers (Hashimoto *et al*., 1973). Interplanted with hybrid poplar with good results in Germany (Knabe, 1973). Tolerant to high pH and salinity in fuel ash in England; suggested as nurse species (Hodgson, 1973).

Eastern Spoils

Speckled and European Alder are fast growing, single-stemmed species which show good adaptation to all classes of Pennsylvania spoils; 87 percent survival on spoils above pH 4.5, 36 percent on spoils with pH 3.5 or below; appear to be free from disease or insect damage (Miles *et al*., 1973; Magnuson and Kimball, 1969; *Revegetation*, 1965). Sixty-eight percent survival (2.0 m (6.4 ft) in height) after five years on Pennsylvania anthracite spoils (pH 4.0-7.0) that were graded; 44 percent survival, 1.3 m (4.2 ft) height on ungraded spoils.

European alder can be planted as an alternative to black locust on West Virginia spoils; not as complete or quick a cover as black locust; can be used for pulpwood production (Brown, 1971). Alder has a good survival rate on spoils in West Virginia with pH as low as 3.5; less vigorous, but more disease resistant than black locust; resists livestock grazing (Ruffner, 1966). Classified as a pioneer species on West Virginia gob piles (Coalgate, 1973).

Good results on Kentucky spoils (pH 3.5-7.5) (Revegetation Manual, 1966; Carter et al., 1974). Eighty percent survival, 3.7 m (12.2 ft) height after five years on eastern Kentucky spoils with pH 3.5-5.5; good nurse species, provides shade and fixes nitrogen, helps growth of other species (Dale, 1963).

European black alder had the highest survival (80-98 percent) of trees planted on Ohio spoils in the Cincinnati area (Hill, 1968). Eighty-five to one-hundred percent survival, 0.6 m (2 ft) in height on loose shaly clay of Ohio spoils after two years at pH 5.0-7.0 (Funk and Krause, 1965). Preferred for strip mine reclamation because of easy establishment, rapid growth, abundant leaf litter production and ability to fix nitrogen for associated trees (Funk, 1973). Good results in plantings on poor sites where other species fail; used for plywood and other pulpwood production (Ibid.).

European grew on Georgia kaolin spoils which were deficient in nitrogen and phosphorus (May et al., 1973). Good growth with European on acidic spoils with pH 2.0-3.0 overlaid with 5 cm (2") municipal sewage effluent (Dickerson, 1971).

Mineral Tailings

Good results on Pennsylvania iron ore tailings for European; seedlings were planted in hydroseeded cover of paper pulp mulch, grass seed, sulfur and fertilizer; attained 0.9 m (3 ft) in four months (Francis, 1965).

ALFALFA: Medicago sativa

Perennial legume.

Eastern Spoils

Recommended for spoils having a pH of 6.0 or greater in Pennsylvania (Guide for Revegetating..., 1965) and West Virginia (Mellinger *et al*., 1966), and a pH of 6.5 or greater in Kentucky (Carter *et al*., 1974); Revegetation, 1966).

Alfalfa grew well on Ohio spoils, except on sandy spoils in the southern part of the state, where lespedezas grew (Struthers, 1960). It does not spread by seed, and so may be lost from planting mixtures if overgrazed (*Ibid*.). It is more persistent than clover (Carter *et al*., 1974). A weevil-tolerant variety like Lancer or Weevilchek should be used (*Ibid*.). Good results were obtained growing Iriquois alfalfa on toxic spoils (pH 2.0-3.0) overlaid with municipal sewage effluent and sludge (Sopper *et al*., 1974). Unless fertilized, vigor on West Virginia spoils was poor, and growth was hurt by competition from sweetclover (Ruffner, 1966).

Midwestern Spoils

Recommended as part of grass-legume mixtures for spoils with pH 6.5-7.5 (Crowl, 1962). Good forage crop (*Ibid*.). Good yield on Illinois spoils which were relatively neutral and rich in nitrogen and potassium (Grandt, 1965).

Western Spoils

Recommended for dry subalpine regions in Colorado (Berg, 1975; Townsend, 1975) and for good soils with pH 7.5-8.5 in regions of Montana that receive at least 25-36 cm (10-14 inches) of precipitation per year (Thornburg, 1975). Lakad 65 is a drought-resistant, winterhardy variety for sandy and loamy soils in Colorado (Townsend, 1975). Susceptible to gopher damage (Berg, 1975). May cause bloat if grazed (Townsend, 1975).

Mineral Tailings

Grown successfully on Tennessee phosphate wastes (Morgan and Parks, 1967), and mixed with bromegrass on heavily fertilized alkaline iron tailings in northern Michigan (Shetron and Duffek, 1970). Poor results were obtained in plantings on copper tailings in Nevada (Shirts *et al*., 1974) and Washington (Shirts, 1975). Germinated on leached copper tailings in Utah, but did not do as well as yellow sweetclover (Nielson and Peterson, 1972).

ALKALI SACATION: Sporobolus airoides

A perennial bunchgrass, which grows in moderately alkaline soil from South Dakota to eastern Washington south to Texas and southern California (Hitchcock, 1935). Recommended for revegetation of saline and alkaline spoils in the northern Great Plains, and for western desert areas with a least 20 cm (eight inches) of precipitation per year (Cook et al., 1974).

APPLE TREES: Malus sp.

Growth confined to North America, western and southeastern Europe, central, southern and eastern Asia (Sargent, 1933). Hulls Deer Apple is vigorous, has good winter fruit retention but needs nitrogen additives (Ruffner, 1966). Good results obtained in eastern Kentucky spoils at 490 m (1600 ft) elevation; pear and peach also tried with poor results ("Flexible Mountaintop...," 1964).

ARROWWOOD: Viburnum dentatum

Shrub. Survived 10 years (Hart and Byrnes, 1960). Good survival except on very acid spoil banks, not as good as black chokeberry (Ibid.). Best results when planted on spoils with pH 5.0 or greater and slopes 25 percent angle or less, medium to heavy fruit production (Revegetation, 1966; Hart and Byrnes, 1960).

ASH: Green - Fraxinus pennsylvania
White - F. americana

Eastern Spoils

Green produced little growth or vigor on Pennsylvania bituminous spoils after four years (Miles et al., 1973). Green is good first year then declines; Oyster Shell Scale severely damages tree (Wheeler, 1965). Green and White had fair survival (68 percent after 10 years), slow growth, little litter deposition, damaged by cicada, scale and aphids (Hart and Byrnes, 1960). Particularly poor results on upper slopes of Pennsylvania spoils (Ibid.).

White volunteers on West Virginia spoils (Mellinger et al., 1966). Ninety-three percent survival, 1.8 m (5.9 ft) height on ungraded eastern Kentucky spoils (pH 3.5-5.5, silty clay shale) in pure stands and 85 percent survival, 2.3 m (7.4 ft) height in mixtures with European Alder (Dale, 1963).

Eight-four percent survival of white ash on unfertilized Ohio spoils (pH 5.0-7.0, loose shaly soil) after two years; 64 percent survival on fertilized spoils (Carter et al., 1974). Good results of White and Green on spoils at pH 4.5-8.0; nurse species aids growth (Ibid.). Green is adaptable to plantable Ohio spoils, best suited to moist sites, should be planted in mixtures with black locust on barren spoils banks (Finn, 1958). Good results obtained for white ash planted on lower slopes and bottoms of Ohio spoils having a high percentage clay and loam, will tolerate graded banks having high clay content, can be planted in mixtures with black locust (Ibid.). White survived despite heavy herbaceous cover (Limstrom, 1964).

Midwestern Spoils

Good survival on Midwestern spoils (pH 6.0-7.5) when planted on lower slopes and graded banks, 0-25 percent mixture, recommended for sands and loose or compact soils and clays (Limstrom, 1960). Good results on Midwestern spoils in mixtures with other hardwoods at pH 4.0-8.0, (Crowl, 1962).

Poor growth on neutral southern Illinois spoils after 16 years (Ashby and Baker, 1968). Seventy percent survival of green ash on ungraded Illinois spoils (pH 5.0-6.0, 40 percent soil content) after 21 years; 79 percent on graded spoils (Chapman, 1967). Good results on lower slopes and bottoms of Illinois spoils at pH greater than 5.5, can be planted with sweetclover or other low plants (Boyce and Neebe, 1969). Green is adaptable to all spoil banks, can be underplanted with black locust, subject to severe injury by rabbits (Limstrom and Merz, 1954). White more adaptable than Green, tolerant of compact soils where clay is graded, subject to rabbit damage (Ibid.).

Green and White best suited for planting on Indiana spoil banks having a dense cover of sweetclover, can be grown on acid loams and silty shales (Deitschman and Lane, 1952). Sixty-six percent survival of green ash after 10 years on Indiana spoils.

Good survival and growth of green ash on Kansas, Missouri and Oklahoma spoil banks, best in moist locations, 63 percent survival after 6 years, tolerates competition (Clark, 1954). Mix with black locust for quick cover (Ibid.). Twenty-six percent survival, 2.3 m (24 ft) height of green ash on Kansas spoils (pH 5.6-6.1) after 22 years, damaged by locust (Geyers and Rogers, 1972; Seidel and Brinkman, 1962).

Western Spoils

Good results on Montana spoils with pH 7.5-8.5, coarse soils, overlaid with topsoil and 25-36 cm (10-14 inches) of precipitation per year (Thornburg, 1975). Green ash is sensitive to nutrient conditions, survival related to exchangeable aluminum, soluble salt concentrations and pH; rated excellent for coal spoil revegetation (Lorio and Tatherum, Iowa Res. Bull. 535).

ASPEN: *Populus tremuloides*
P. grandidentata

Large fast-growing trees (Sargent, 1933). In the extreme north, often forms large forests, common on bottom-lands of streams and on high mountain slopes (Ibid.). Excellent volunteering species (Mellinger et al., 1966; Medve, 1973; Revegetation, 1965). Good results obtained in Colorado alpine regions 3,000 m ((10,000 ft) and greater elevation (Brown, 1974). Raube (1969) recommends aspen for planting on acid spoils in mixtures.

AUSTRIAN PINE: *Pinus nigra*

Conifer found in central and southern Europe and northeastern United States (Sargent, 1933).

Eastern and Midwestern Spoils

Tolerant of drought and alkalinity, more sensitive to frost than other pines (Bureau of Mines, 1961). Compatible with sod, annual plants, and light brush (Bureau of Mines, 1961). Sopper et al., (1975) report good survival in laboratory tests on Pennsylvania anthracite spoils at pH 3.0 along with red and white pine. Fifty-one percent survival after five years on graded anthracite spoils at pH 4.0-7.0;

22 percent on ungraded spoils (Czapowskyj, 1970). Average survival on other Pennsylvania spoils, 74 percent; 78 percent on spoils with pH above 4.5, 2 percent at pH below 3.5 (Magnuson and Kimball, 1969). Poor specimen on bituminous spoils, 25 percent or less on slopes with pH greater than 5.0 (Guide for Revegetating..., 1965). Planted in West Virginia as ornamental species, but too early to recommend for forestation (USBM, Circular 109, 1960).

Produced good results on Midwestern spoils at pH 4.0-7.5, good wildlife cover (Crowl, 1962).

Mineral Tailings

Produced good cover and stabilization, excellent growth 3-7.6 m ((10-25 ft) in height) and adaptation on Arizona copper tailings (Ludeke, 1972; 1974).

BAHIAGRASS: Paspalum notatum

Rhizomatous perennial grass, grows primarily in the southeast (Hitchcock, 1935). Recommended for poor sites in southeastern beach areas--tolerates salt spray (Graetz, 1973). A good grass for growth in central Alabama, and the only suitable grass found for southern Alabama (Dickens and Orr, 1969). Requires 4.5 g/m^2 (40 lbs of nitrogen per acre) per year, but does not respond to phosphorus or potassium addition (Ibid.). Lower yield than coastal bermudagrass on kaolin clay spoil in Georgia (May et al., 1973). Recommended for erosion control on sand and gravel extraction sites (Schellie and Rogier, 1963). Does well on dikes and around slime pits in Florida phosphate wastes (Craig, 1975).

BALD CYPRESS: Toxadium distichum

Resinous trees, found in river swamps, usually submerged several months of the year throughout the eastern U.S., Gulf states and part of the Midwest (Sargent, 1933). Ruffner (1966) reported slow growth on West Virginia spoils with stands below 50 percent. Fair survival on Pensylvania spoils but good growth rate (Miles et al., 1973). Grew slowly on western Kentucky spoils and suffered blot crown (Boyce and May, 1948). Crowl (1962) reported fair results on Midwest spoils with pH 5.5-6.5 but subject to bagworm.

BAMBOO: Wild - Similax auriculata

Perennial grass, usually large, sometimes tree-like, woody, rarely herbaceous or climbing; of wide geographical range (Bailey, 1942).

Graetz (1973) reported success by direct seeding on sand dunes on the North Carolina coast.

BANKS PINE (see Jack Pine)

BARLEY: Hordeum vulgare

An annual grass, normally grown in the western United States but also found in the Northeast (Hitchcock, 1935). Winter barley germinated quickly and grew rapidly on saline-alkaline copper tailings in Arizona and provided good cover and erosion stabilization (Ludeke, 1974). Winter barley has also been used to stabilize gold mine tailings in Sourth Africa (Stabilizing Mine Dumps, 1968). A special variety, Charlottetown 80, grown on Prince Edward Island by the Canadian Department of Agriculture, is highly resistant to aluminum toxicity and grows in acidic wastes with pH as low as 3.0 (Dean et al., 1971; Hill, 1971).

BEACHGRASS: American - Amophilia breviligulata
European - A. arenaria

Rhizomatous perennial. American beachgrass is grown along the eastern coast from Maine to North Carolina, and on the shores of the Great Lakes from Lake Ontario to Lake Superior and Lake Michigan. European beachgrass (also known as marram) is found along the northwest coast from San Francisco to Oregon (Hitchcock, 1935). American beachgrass is dominated by sea oats on beaches below North Carolina (Woodhouse et al., 1968). Suggested for rapid stabilization of sand and gravel pits (Ruffner and Steiner, 1973). An attempt to grow American beachgrass on an acid coal mine spoils neutralized with fly ash yielded poor results (Capp and Gillmore, 1974). European beachgrass has been used to stabilize sand tailings from South African gold mines (James, 1966).

BENTGRASS: Fine - Agrostis tenuis

Annual or perennial grasses with erect or creeping stems and open panicles of small flowers (Bailey, 1942). Fine bentgrass occurs throughout the Northeast and along the northwest coast (Hitchcock, 1935). Strains of this grass have been developed in Wales which are tolerant to aluminum, copper, iron and zinc (Goodman et al., 1973).

BERMUDAGRASS: Cynodon dactylon

Rhizomatous perennial which grows primarily in the Southeast (Hitchcock, 1935). Recommended as the best grass for the southeastern and southwestern United States--tolerates drought and high temperatures, and spreads vigorously (Schellie and Rogier, 1963).

Common bermudagrass can be planted both by seeding and plugging; it needs both nitrogen and phosphorous fertilizationand is not well adapted to acidic soils (Mays, 1975). Coastal bermudagrass is good for sandy soils in the Southeast, needs fertilization, and cannot be seeded (Graetz, 1973); it has been used to revegetate a kaolin clay spoil in Georgia (May et al., 1975).

Giant bermudagrass has been established both by broadcast seeding and plugging on fertilized copper mine tailing berms in Arizona (Day and Ludeke, 1973). Best results were obtained by plugging. A 90-100 percent cover was obtained within two years (Ibid.).

BIRCH: Black - Betula lenta
European White - B. pendula
Grey - B. populifolia
River - B. nigra
Yellow - B. lutea

Trees with smooth resinous bark (Sargent, 1933). Widely distributed from the Artic Circle to Texas, southern Europe, the Himalayas, China and Japan; some species form great forests at the north or cover high mountain tops (Ibid.).

Eastern Spoils

Grey birch produced good results whenever planted and was reproducing effectively in less than 10 years (Davis and Melton, 1963). Useful as initial cover and soil conditioner on the less favorable spoils and steeper slopes in Pennsylvania (*Ibid*.). Acid tolerant (Wheeler, 1965). Grey did not survive on ungraded breaker refuse even after hydroseeding and liming; poor results on graded spoils after same treaments (Czapowskyj and Writer, 1970). Mixtures of European, grey and red pine produced good results for highly acid Pennsylvania spoils (*Revegetation* 1965). Black and river birch invade spoils (Bramble and Ashley, 1955).

European white and grey produced best survival rate on West Virginia spoils with pH below 3.5 (Coalgate, 1973). Brown (1960) and Mellinger *et al*. (1966) both reported that black birch volunteers on West Virginia spoils. Ruffner (1966) reports that seedings in spring and fall produce the best results.

River birch produced good results on Kentucky spoils at pH 4.0-7.5 (Carter *et al*., 1974). Should be planted in a mixture with other hardwoods (*Ibid.*).

Mineral Tailings

Grey produced good results on Pennsylvania iron ore tailings at pH 8.9 (Francis, 1964).

BIRDSFOOT TREFOIL: *Lotus corniculatus* (see also Narrowleaf Trefoil)

Long-lived perennial, cool season flowering legume.

Eastern Spoils

Recommended for spoils with pH of 5.0 or greater in Pennsylvania (*Guide for Revegetating*..., 1965; Miles *et al*., 1973) and Ohio (Hill, 1968), pH 4.5 or greater in Kentucky (Carter *et al*., 1974; Vogel and Berg, 1968) and pH 5.5-6.0 or greater in West Virginia (Mellinger *et al*., 1966; Ruffner, 1966). Establishment may be difficult, and may require extensive liming, fertilization and mulching (*Revegetation*, 1966; Ruffner, 1966; Struthers, 1960). Tolerant to manganese (Berg and Vogel, 1968). Once established, it frequently provides better cover than sweetclover, alfalfa and lespedezas (Hill, 1968; Struthers, 1960; Vogel and Berg, 1968). Recommended for high elevations (Carter *et al.*, 1975; Ruffner, 1966). Best sown in spring (*Revegetation*, 1966). Must be inoculated before seeding, and is susceptible to damage by quick cover species (Carter *et al.*, 1974).

Good results were obtained when birdsfoot trefoil was planted on a pH 2.0-3.0 spoil overlaid with municipal sewage effluent and sludge (Sopper *et al.*, 1974). Capp and Gillmore (1974) successfully grew Empire birdsfoot trefoil on an acid spoil treated with fertilizer and alakaline fly ash, but had no success with common birdsfoot trefoil.

Midwestern and Western Spoils

Recommended for relatively neutral, nutrient-rich soils (Crowl, 1962; Grandt, 1965). Excellent germination and growth in mixture with grasses on acidic spoils in Illinois; tolerated drought very well (Sorrell, 1974). Cannot withstand competition from quick cover crops (Crowl, 1962). May persist for several years in upper subalpine regions of Colorado; attractive and palatable to animals (Berg, 1975).

Mineral Tailings

Suggested for copper tailings in Arizona--drought resistant and salt tolerant (Ludeke, 1973).

BLACK CHERRY: *Prunus Serotina*

Trees with bitter aromatic bark and leaves (Sargent, 1933).

Eastern Spoils

Outperformed hybrid poplar on acid West Virginia spoils (Trimble, 1963). Volunteers on Pennsylvania bituminous spoils (Medve, 1974). Common near coasts in sandy soils--Outer Banks of North Carolina and northern South Carolina coast (Graetz, 1973). Good results on sandy soils, moderate salt-spray resistance (*Ibid.*). Showed great response to improved soil nitrogen conditions provided by black locust on Ohio spoils (Finn, 1953).

Midwestern and Western Spoils

Twenty percent survival (less than locust and bur oak) after 22 years on Kansas spoils that were nutrient rich at pH 5.6-6.1 (Geyer and Rogers, 1972). Recommended for cover with black locust (Ibid.). Chapman (1967) reported 62 percent survival on silty clay spoils after 20 years at pH 5.5-7.0 in Kansas and Missouri. Forty-seven percent survival, 11 m (35 ft) height on ungraded spoils and 13 percent, 4 m (13 ft) height on graded spoils (Ibid.). Good results obtained on moist Midwestern spoil sites; tolerates competition (Clark, 1954). Should be planted in mixtures and under decadent black locusts (Ibid.). Adapated to calcareous, loamy and clayey banks in Illinois with high proportion of soil (Limstrom and Merz, 1955). Can be used in underplanting on these spoils; plant in mixtures with black locust and other hardwoods (Ibid.).

Poor results obtained, except under ideal conditions, on coarse Montana spoils that were covered with topsoil, at pH 7.5-8.5 and 36-46 cm (14-18 inches) precipitation per year (Thornburg, 1975).

BLACK CHOKECHERRY: Pyrus melanocarpa
Aronia Melanocarpa

Small deciduous-leaved shrub, excellent growth on drier, rocky soil (Bailey, 1942). Excellent survival, moderate fruit yield, provides food and cover for wild game (Hart and Byrnes, 1960).

BLACK LOCUST: Robinia pseudoacacia

Tree, found on the slopes of the Appalachian Mountains, central and southern Pennsylvania, northern Georgia, southern Illinois and westward to the Ozark region of southern Missouri, Arkansas and Oklahoma, widely naturalized east of the Rocky Mountains (Sargent, 1933). Effective cover in 4-5 years, most vigorous and widely adaptable tree species (Ruffner, 1966).

Good nurse species either in pure stands or in a mixture with black cherry, sycamore and bur oak for quick cover and soil erosion control (Limstrom, 1960; Geyer and Rogers, 1972; Bureau of Mines, 1961). Good results obtained on nutrient rich, ungraded soils at pH 5.6-6.1 in mixtures with bur oak, sycamore and loblolly pine (Geyer and Rogers, 1972). Used chiefly for gully control, elsewhere as a nitrogen fixing nurse (Bureau of Mines, 1961). Subject to borer injury (Ibid.). Should not be planted on poorly drained, highly toxic spoils (Ibid.). Best results obtained on well-drained soils (Ibid.). Good results obtained on very acid spoils (pH 2.0-3.0) when overlaid with 5 cm (2") municipal sewage effluent (Dickerson, 1971).

"Dominant Stem" black locust (hybrid) gave superior growth rate and has low susceptibility to locust borer (Ruffner and Steiner, 1973).

Eastern Spoils

Rated best species for adaptation on Pennsylvania mine spoils, usually planted in a mixture for better survival rate because of susceptibility to locust borer (Miles et al., 1973). Good nurse for hybrid poplars planted on Pennsylvania spoils, provides lots of litter, stimulates growth of other hardwoods (Kendry, 1973; Hart and Byrnes, 1969). Volunteers in mixture with blackberry, pokeweed, thistles, elderberry, timothy and hickory, maple, oak and cherry (Ibid.). Ninety percent survival obtained when hydroseeded on upper slopes of Pennsylvania spoils and covered with overburden more alkaline than local soil, better than crownvetch and ryegrass (Bureau of Mines, 1973). Good for banks with low soil content and upper slopes in a mixture with Japanese birch (Hart and Byrnes, 1960). On Pennsylvania spoils, mixtures including black locust may be harmful if the black locust should overtop the other species (Ibid.). Excellent response when fertilized with sewage sludge (Sopper, 1968). Volunteers on Pennsylvania bituminous spoils (Medve, 1974).

Excellent survival rate and growth, although poor form and susceptibility to severe damage from the borer seriously limits commercial potential (Davis and Melton, 1963).

Revegetation (1965) reports that it is a good nurse on neutral soil with pH greater than 5.0 and slopes 25 percent angle or less; for erosion control 4.5 g/m^2 (40 lbs) of nitrogen and 9 g/m^2 (80 lbs) of phosphorus should be added. Failed on anthracite breaker refuse even after hydroseeded and limed (Czapowskyj and Writer, 1970). After 5 years, 64 percent survival on graded spoils with pH 4.0-7.0 and 22 percent on ungraded (Czapowskyj, 1970).

Brown and Tryon (1960) reported good results on West Virginia spoils with pH 4.0 or greater, better results as pH increases and slope decreases. Mellinger _et al_. (1966) reported that black locust suffers more damage if planted on spoils below pH 6.0. Should only be planted on level ground (_Ibid_.).

Common black locust is best for quick growth and cover on West Virginia spoils (Ruffner, 1966). Protective cover established after 4 years and soil stabilization after 8 (_Ibid_.). Should not be grazed; "Dominant Stem" and Clone BN-4194 are better species than Common (_Ibid_.). Brown (1962) reported 68.7 percent survival rate on West Virginia spoils (less than red pine, white pine, and yellow poplar). Uniform growth on slopes, nitrogen fixing, good adaptability, provides cover and stabilization (_Ibid_.). Good seed production, rapid juvenile growth (Brown, 1971). Volunteers on West Virginia spoils; November-March best period for direct seeding, should not be planted in low precipitation areas (Brown, 1960). Germination 5 percent greater on northeast facing slopes than southwest facing slopes; however, mortality rate is higher on northeast facing slopes (Brown, 1973). Growth is correlated to slope percent, elevation and the extent of regrading (compaction of the spoil surface); indirectly affected by the amount of moisture available for plant growth, temperature and evaporation losses (_Ibid_.). Indeterminate growth habit; reduction in growth occurred only at elevation above 760 m (2500 ft) (_Ibid_.).

Berg and Vogel (1960) reported black locust to be tolerant to manganese in Kentucky spoils. Should be no more than 25 percent in mixtures to inhibit overtopping (_Revegetation Manual_, 1966). Can be used alone to provide quick cover on steep Kentucky slopes (_Ibid_.). Carter _et al_. reports that black locust can be planted on spoils at pH 4.8 for a rich cover in critical areas; not recommended for large areas.

Proved to be valuable as a nurse crop for shade-tolerant species; however, wind movement of the thorny branches frequently caused severe mechanical damage to other trees planted in a mixture with it (Boyce and Merz, 1959).

Found superior on bare spoils or in a mixture with shortleaf pine in Ohio plantings (Finn, 1953). Nitrogen fixing, excellent nurse for black walnut, black cherry and yellow poplar (Ibid.). Good early survival and growth; stands begin to break up after 7 years on clay sites in Ohio (Ibid.). Mouse girdling has caused severe damage and has been specifically reported on black locust (Bureau of Mines, 1961).

Midwest Spoils

Good results produced on all planting zones with pH 4.0-7.5, recommended for sands or loose loams and clays (Limstrom, 1960). Competes successfully on loose, shaly clay Kansas spoils with pH 7.5 or greater (Seidel and Brinkman, 1962). Caused severe damage to red cedar and sycamore when planted in mixtures (Ibid.). Geyer (1971) reports successful stabilization, rapid spreading, early crown closure. Unaffected by grading, subject to borers, crooked stems; dies back (on graded lands) (Geyer, 1971; Chapman, 1967). Most trees died after 20-21 years on spoils with pH 5.0-6.0 (40 percent survival); in Kansas and Missouri spoils with pH 5.5-7.0, 58-63 percent survival (less than sycamore, loblolly, buoab, red cedar or shortleaf pine) (Chapman, 1967).

Good results obtained in plantings on Illinois spoils; fast early growth, ability to spread by root sprouts (Boyce and Neebe, 1959). Added nitrogen to soil which was in short supply on newly mixed areas (Ibid.). Will survive on all plantable spoils; growth and development varies with each site (Limstrom and Merz, 1954).

Seventy-four percent survival rate after years on Indiana spoils; 85 percent with height of less than 7.6 m (25 ft) (DenUyl, 1962). Can be planted on highly erosive banks and used as a stabilizer and cover (Deitschman and Lane, 1952). Medvick (1973) states that black locust was abandoned permanently in 1956 as a species for Indiana spoils.

Mineral Tailings

Good results after two years on fertilized northern Michigan irom ore tailings at pH 7.8-8.1 (Shetron and Duffek, 1970). It was found that fertilization hurt survival (Ibid.). Red pine did better in general on tailings (Ibid.).

BLACK WALNUT: Juglans nigra

Tree found throughout the North and Southeast, Midwest and Gulf States of the United States; most abundant in regions west of Allegheny Mountains and western slopes of mountains in Tennessee and North Carolina (Sargent, 1933).

Eastern Spoils

Good results on northeastern spoils when seeded with treated seed rather than planted (Bureau of Mines, 1961). Damaged in mixed plantings with black locust on Pennsylvania spoils (Hart and Byrnes, 1960). Growth and survival best on lower slopes and in bottom-lands on Kentucky spoils (in a mixture with black locust) (Boyce and Merz, 1948). Unsuitable for planting in pure stands (Ibid.).

Thirty-three percent survival after 2 years when seeded on loose, shaly clay of Ohio spoils (pH 5.0-7.0) (Funk and Krause, 1965). Should not be planted on sandy soil; best results on lower, ungraded slopes at pH 5.5-8.0; nurse species aids growth (Carter et al., 1974; Finn, 1953).

Midwestern Spoils

Good results obtained, light to heavy cover, when planted on lower slopes and ungraded banks (pH 6.0-7.5) with loose or compact sands or clays (Limstrom, 1960). Crowl (1962) reports good results in all areas at pH 5.0-8.0 with the use of stratified nuts or seedlings. Tolerates heavy competition on Kansas, Missouri and Oklahoma spoils; good for mixed plantings on moist sites (2-3 seeds/spot planted) (Clark, 1964).

Adapted to loamy and clayey Illinois banks in mixtures with black locust or other hardwoods, at pH 6.5-8.0 (Limstrom and Merz, 1954; Boyce and Neebe, 1959). Unsuitable for planting in pure stands or acidic spoils, better growth on calcareous spoils (Boyce and Neebe, 1959). Good growth rates on neutral spoils, 2.4 m (8 ft) (4 years), 4.9 m (16 ft) (8 years), 9.8 m (32 ft) (12 years), 14 m (47 ft) (16 years) (Ashby and Baker, 1968). Chapman (1967) reported 60 percent survival for seeds (35 percent for trees) on ungraded Illinois spoils at pH 5.0 and 40 percent soil, 62 percent survival for seeds (18 percent for trees) on graded soils. Thirty percent survival after 10 years on Indiana spoils (DenUyl, 1962).

Eighteen percent survival, 10 m (34 ft) height on ungraded Kansas and Missouri spoils; failed on graded spoils (Chapman, 1967). Pure stands had better survival on Kansas spoils (pH 7.5, loose, shaly clay) than in mixtures with black locust (Seidel and Brinkman, 1962). Can be mixed with bur oak, sycamore, red cedar or green ash (*Ibid*.).

Mineral Tailings

Growth was poor on saline-alkaline Arizona copper tailing slopes; nurse was needed (Ludeke, 1974). Good cover on other Arizona tailings; uninjured by early frost (Ludeke, 1972).

BLADDER SENNA: *Colutea arborescens*

Deciduous shrub, good growth on sandy soil (Bailey, 1942). Not as vigorous as autumn olive; palatable to wildlife (Ruffner, 1966). Tolerant to high pH and salinity (Hodgson, 1973). Adaptable to areas where temperature does not go below zero during the year (Ruffner, 1966). It is not nitrogen fixing (*Ibid*.).

BLUEGRASS: Canada - *Poa compressa*
Kentucky - *Poa pratensis*

Cool season perennial grass. Canada bluegrass grows primarily in the Northeast, and Kentucky bluegrass is found throughout the northern United States (Hitchcock, 1935).

Eastern, Midwestern and Western Spoils

Bluegrass tends to become established slowly, and so should only be planted in mixtures with more rapidly growing species. Kentucky bluegrass is recommended for Pennsylvania spoils with pH greater than 5.0 (*Guide for Revegetating*..., 1965). Poor results were obtained after one year with Kentucky bluegrass in Ohio (Hill, 1968), and with both Canada and Kentucky bluegrass in West Virginia (Ruffner, 1966). Crowl (1962) recommends a mixtue of Kentucky bluegrass and legumes for neutral Midwestern spoil reclamation. Berg (1975) observed poor bluegrass seedling vigor but persistent growth of established stands in subalpine regions of Colorado; he also found that Kentucky bluegrass was preferable on moist sites, and that Canada bluegrass was harder to establish but better adapted to dry sites.

Mineral Tailings

Canada bluegrass has been used with moderate success on fertilized uranium tailings in Colorado (Shirts, 1975). Kentucky bluegrass is part of a seeding mixture for gold mine tailings in South Africa (Stabilizing Mine Dumps, 1968), and is cited as a promising grass for mineral tailings revegetation in the Southwest (Dean *et al*., 1971).

BLUE PALO VERDE: *Cercidium floridum*

Trees or shrubs, found in southern Texas and northern Mexico (Sargent, 1933). Excellent results obtained on Arizona alkaline-saline copper tailings (Ludeke, 1974). Survives drought; better results when watered and fertilized; grows to 7.6 m (25 ft) (Ludeke, 1973).

BLUE SPRUCE: *Picea pungens*

Pyramidal trees with tall tapering trunks (Sargent, 1933). Found primarily in western United States at higher elevations (2000-3400 m) (6500-11,000 ft) (*Ibid*.). Shirts *et al*. (1974) reported almost complete failure on Nevada copper tailings, 2000 m ((6500 ft), 21 cm (8.3 inches) of precipitation per year) even after fertilization and stabilization with Coherex.

BLUESTEM: Big - *Andropogen gerardi*

Perennial bunch-type grass. Slow to become established on moderately acid soils in Pennsylvania, but stands improve with age (Miles *et al*., 1973). Fair results in West Virginia plantings (Ruffner, 1966). Failed in acid spoil treated with fly ash (Capp and Gillmore, 1974).

BOTTLEBRUSH SQUIRRELTAIL: *Sitanion hystrix*

Grass native to the western United States. Invades older spoil banks in Wyoming, and becomes dominant in stable areas after 15 years; has also been observed to volunteer in test plantings of other species (May *et al*., 1971).

BRISTLECONE PINE: *P. aristata*

Resinous small tree with short trunk, found from California to Colorado (Bailey, 1942; Chittendon, 1956). Survived on untreated Pennsylvania iron ore tailings with pH 8.7 (Francis, 1964).

BRISTLY LOCUST: Robinia fertilis

Legume or shrub, nitrogen fixing, found in the United States and Mexico (Sopper et al., 1974; Revegetation Manual, 1965; Sargent, 1933).

Eastern and Midwestern Spoils

Seventy-eight percent survival on Pennsylvania spoils at pH 4.0. Arnot bristly locust had better survival and more plant vigor (McWilliams, 1971). Rapid growth, provides dense canopy and good adaptability, excellent for establishment of ground cover on barren sites (Miles et al., 1973; McWilliams, 1970). Well suited for use on steep banks of spoils and cutbanks of construction projects (McWilliams, 1970). Plants did not survive on highly acidic spoils immediately adjacent to exposed seams (Ibid.). Fifty-five percent survival on Pennsylvania bituminous spoils at pH 4.5 or above and slopes of 25 percent or less (Magnuson and Kimball, 1969; Revegetation, 1965). Excellent for erosion control on steep outer slopes with heavy seeding (Miles et al., 1973; Ruffner, 1965). Good results on highly toxic Pennsylvania spoils (pH 2.0-3.0) overlaid with 5 cm (2") municipal sewage and 5 cm (2") sludge per week; best legume for acid spoils (Sopper et al., 1974; 1975). Best coverage of any grass or legume, third to weeping lovegrass and deertongue in dry matter production (Ibid.).

Arnot bristly locust produced good results on spoils at pH 3.5 or greater, grew 2.4-3.0 m (8-10 ft), abundant seed production (Ruffner and Steiner, 1973). Arnot had high vigor and rapid development; spreading, thicket-forming growth habit is good for erosion control (McWilliams, 1970). Provides a dense canopy in summer and good leaf litter; shows adaptability on spoils at pH 4.5-7.5; ideally suited for conservation (Ibid.).

Sixty-seven percent germination of 50°C on dark Kentucky spoils (pH 4.0-7.5); mulching important (Revegetation, 1966; Carter et al., 1974). Palatable to livestock; good growth and cover; effective erosion control on Kentucky spoils; acid tolerant (Ruffner, 1966; Carter et al., 1974, Revegetation Manual, 1966).

One of several recommended shrubs of Midwestern acid spoils (Carter et al., 1974).

Mineral Tailings

Good cover, 3-4.6 m (10-15 ft) height, excellent adaptability on Arizona tailings (Ludeke, 1972).

BROMEGRASS: Field - Bromus arvensis
Smooth - Bromus inermis

Smooth bromegrass is a rhizomatous perennial found primarily in the northern United States west of Ohio. It is cultivated as hay and pasture grass (Hitchcock, 1935). Field bromegrass is a cool season annual grass.

Eastern, Midwestern and Western Spoils

Field bromegrass is recommended as a quick cover grass for fall seedings in Kentucky on spoils with pH greater than 5.0; however, it may compete with and retard the growth of permanent species (Carter *et al.*, 1974; *Revegetation Manual*, 1966).

Smooth bromegrass is recommended for netural spoils in Pennsylvania (*Guide for Revegetating...*, 1965), and was used in a mixture with alfalfa to revegetate an acid spoil in Ohio (Krause, 1964). In another reference to Ohio spoil reclamation, it is rated as satisfactory but difficult to handle beacuse of its large seed (Struthers, 1960). It performed poorly in West Virginia (Ruffner, 1966) and failed in tests on acid spoil overlaid with municipal sewage effluent and sludge (Sopper *et al.*, 1974).

Crowl (1962) recommends smooth bromegrass for revegetation of neutral Midwestern spoils, noting its value for wildlife cover and forage. Smooth bromegrass is also recommended for subalpine regions in the Rocky Mountains; it is reportedly easy to handle and grows persistently, but has a high nitrogen requirement and is susceptible to gopher damage (Berg, 1975; Eamon, 1974). It generally did well in transplants in Montana, but not from seed and performed poorly on wet soils (Farmer *et al.*, 1974; Thornburg, 1975).

Mineral Tailings

Smooth bromegrass was used in combination with alfalfa on iron ore tailings in northern Michigan (Shetron and Duffek, 1970), and did well after three months on acidic copper tailings in Washington which had been heavily limed, fertilized, and treated with sewage sludge (Shirts *et al.*, 1974). In the latter tests fescue and wheatgrass also worked well, and orchardgrass and alfalfa failed.

BROOMSEDGE: *Andropogon virginicus*

Perennial grass. Invaded plantings in Pennsylvania (Bramble and Ashley, 1955) and West Virginia (Ruffner, 1966). Attempts to establish by broadcasting seed on outer slopes in West Virginia were unsuccessful (*Ibid*.).

BUFFALOBERRY: *Sherperdia argentia*

A shrub, 4.9-5.5 m (16-18 ft) in height, native from Manitoba and Saskatchewan south to Colorado, Nevada and New Mexico, now grown in upper Mississippi Valley and northward (bailey, 1942). Poor results on dry soils (Thornburg, 1975). Good cover obtained on saline-alkaline Montana spoils with coarse wet soil, pH 7.5-8.5 and 25-36 cm (10-14 inches) of precipitation per year (*Ibid*.).

BUFFEL GRASS: *Pennisetum ciliare*

Warm season rhizomatous perennial grass which reproduces by seed (Ludeke, 1973). Grows in sand, but prefers heavy clay soils (*Ibid*.). Used in phosphate tailing sands in Florida, but was slow to establish (Craig, 1975). It was used successfully to revegetate saline-alkaline copper tailings in Arizona, and was the only grass to yield a high cover density when hydroseeded (Ludeke, 1974).

CACTI: *Cactacea*

Succulent trees or shrubs with copious watery juice (Sargent, 1933). Ludeke (1974) reported success on Arizona copper tailings with Saguaro. Resistant to rodent activity, drought, dessication and sunscald (*Ibid*.). Other types of cacti can be transplanted to tailing slopes; best transplant species are prickly pear, octillo, cholla and yucca (*Ibid*.). Saguaro grows slowly to 15 m (50 ft) on Arizona tailings (Ludeke, 1972). Smaller unbranched specimens are easily transplanted (*Ibid*.). Prickly pear provides good growth when propagated either by vegetative means or from seed (*Ibid*.).

CARAGANA (Siberian Pea Tree): Caragana arborescens

Small tree, one of the best hedge shrubs for the prairies of the Northwest (Bailey, 1942). Poor results on Indiana bituminous mine spoils (Ruffner, 1965). Did not germinate on Nevada copper tailings 2000 m (6500 ft) with 21 cm (8.3 inches) of precipitation per year) even after fertilization and treatments of Conerex (Shirts *et al*., 1974). Good results obtained in same regions when root-transplanted (*Ibid*.). Good results on dry coarse soils of Montana tailings with pH 7.5-8.5 and 25-36 cm (10-14 inches) of precipitation per year (Thornburg, 1975). Poor results on wet, saline-alkali soils (*Ibid*.). May *et al*. (1971) reported 50 percent survival on irrigated Wyoming spoils, 8 percent on non-irrigated spoils (pH 6.4, high clay content, 23.93 cm (9.42 inches) of precipitation per year).

CEDAR: Northern White Cedar - Thuja occidentalis
Eastern Red Cedar - Juniperus virginiana

Northern white cedar is a tree with a short, often lobed and buttressed, trunk; Eastern red cedar is a tree with an often lobed, eccentric and frequently buttressed trunk (Sargent, 1933).

Eastern Spoils

Eastern red cedar is promising in dune areas; prefers alkaline sandy soils; needs protection from wind (Graetz, 1973). White cedar is slow growing; tolerates wetness and high pH (Bureau of Mines, 1961). Planting failures due to heavy competition; will hold in spoils with pH 6.0 or above or in spoils with limed upper subsoils (*Ibid*.). White is tolerant of poor drainage and lime; should be planted with caution except at higher elevations (*Ibid*.). Red cedar is tolerant of alkalinity and drought (*Ibid*.). Good results in pure stands or in a mixture with black locust on calcareous Ohio spoils (Finn, 1958). Eastern red produces good results on Ohio spoils at 5.0-8.0; should not be planted on graded banks with compact soil materials (Carter *et al*., 1974). Both Eastern and Northern survived well with heavy herbaceous cover (Limstrom, 1964). On silty clayey Ohio spoils, white cedar had an 86.3 percent survival after 2 years; red cedar had 61.7 percent--outperformed all other pine species (Lowry, 1969).

Midwestern and Western Spoils

Red cedar and white cedar are recommended for Midwestern spoils with pH 6.0-7.5, on sands and loose or compact loams and clays (Limstrom, 1960). Good results with red cedar on soils at pH 5.0-7.0, grown under black locust (Crowl, 1962). Chapman (1967) reported 35 percent survival on ungraded silty, clayey spoils in Illinois (pH 5.0-6.0, 40 percent soil) and complete failure on graded spoils. Eighty-seven percent survival on silty, clayey, ungraded Kansas and Missouri spoils (pH 5.5-7.0, sixty-three percent soil) and 11 percent survival on graded spoils (Ibid.). Eastern grew in mixtures with black walnut on loose, shaly clay Kansas spoils at pH 7.5 (Seidel and Brinkman, 1962). Some locust damage (Ibid.). Geyer and Rogers (1972) reported 24 percent survival, after 22 years, of eastern red cedar on nutrient rich Kansas spoils at pH 5.6-6.1 (less than shortleaf, bur oak, black locust but better than other pines). Eastern red cedar produced good results (42 percent survival after 6 years, 1.5 m (5 ft) average height) on calcareous, mildly acidic banks in Kansas, Missouri and Oklahoma (Clark, 1954). Slow growth on acid sites; tolerates competition (Ibid.). Red cedar should not be planted near or in apple orchards; it is an alternate host for cedar-apple rust (Ibid.).

Best results obtained on calcareous upper and lower slopes in Illinois and Indiana (Boyce an Neebe, 1959; Limstrom and Merz, 1954). Slowest growth on highly toxic spoils in both areas; red cedar can be planted in mixtures with pine or hardwoods (Ibid.). Deitschman and Lane (1952) reported that red cedar could be grown on Indiana spoils for Christmas trees or greens; best suited for planting on a bank having a dense cover of sweetclover.

Seventy-nine percent survival rate of Eastern red cedar on Iowa spoil banks; poor results on spoils with exchangeable aluminum and soluble salt concentrations (Lorio and Gatherum, 1966).

CHESTNUT OAK: Quercus montana

Trees or shrubs, found on hillsides and high rocky banks of streams (Sargent, 1933). Ruffner (1966) reported chestnut oak not as good as red oak; however, too early to evaluate completely. Limstrom (1960) recommended planting on sands or loose loams and clays with pH 5.0-6.0.

Mineral Tailings

White clover has been grown with timothy grass on fertilized alkaline iron ore tailings in northern Michigan (Shetron and Duffek, 1970). Red clover was grown on limed phosphate wastes in Tennessee (Morgan and Parks, 1967).

CORALBERRY: *Symphorecarpos orbiculatus*

Deciduous upright or, rarely, prostrate shrub, 0.6-1.5 m (2-5 ft) tall (Bailey, 1942). Crowl (1962) reports good results on Midwestern spoils with pH 5.0-6.5 as cover crop under black locust.

COTTONWOOD: Plain - *Populus tremuloides*
Eastern - *Populus deltoides*

Large, fast-growing tree (Sargent, 1933).

Eastern Spoils

Considerable volunteering on Pennsylvania bituminous spoils (Medve, 1974). Good vigor and form shown by seedling; good cover, best results on West Virginia spoils at pH 4.0 (Ruffner, 1966). Forty percent survival in pure stands on ungraded eastern Kentucky spoils (pH 3.5-5.5, silty, clay shale), 60 percent survival in mixture with European alder (Dale, 1963). Good results when planted in bands or blocks on western Kentucky and Ohio spoils (Carter *et al*., 1974). Should not be planted on upper slopes of ungraded banks with coarse or loose soils in pure stands (*Ibid*.). Hill (1968) reported erratic survival, but generally good results. Adaptable to a wide variety of spoils; a good plant stock is essential (Finn, 1958).

Midwestern Spoils

Fast growing in pure stands on all Midwestern spoils at pH 5.0-8.0 (Crowl, 1962). Light cover, good growth on slopes and graded banks (pH 6.0-7.5); recommended for sands and loose or compact loams and clays (Limstrom, 1960).

Sixty-two percent survival, 18 m (60 ft) height on ungraded Illinois spoils (pH 5.0-6.0, forty percent soil, mostly silt and clay) after 21 years; 40 percent, 12 m (40 ft) on graded soils (Chapman, 1967). Established naturally and by planting on all Illinois spoils; better growth and development on loamy and clayey banks (Boyce and

CICER MILKVETCH: Astragalus cicer

Rhizomatous legume used in several western spoil reclamation efforts. Adaptable to dryland conditions in the central Great Plains; does not grow as well as alfalfa, but unlike alfalfa does not cause cattle bloat (Townsend, 1975). It has done well on coarse wet, alkaline, north- and east-facing slopes in Montana, and poorly under all other conditions (Thornburg, 1975). It makes poor fodder, displays weak vigor and is susceptible to gopher damage in Colorado subalpine regions (Berg, 1975), and is considered to have little or no value for mine spoil reclamation in Wyoming (Tresler, 1975).

CLOVER*: Alsike - Trifolium hybridum
Ladino - Trifolium repens ladino
Red - Trifolium pratense
White - Trifolium repens

Nitrogen fixing legume, useful as feedstock (as pasturage or hay) or as a green manure (Bailey, 1942). Eastern Spoils

Red and white clovers are recommended for spoils in Pennsylvania with pH 5.0 or greater (Guide for Revegetating..., 1965) and spoils in Kentucky with pH 6.0 or greater (Carter et al., 1974; Revegetation, 1966). Ladino clover and Pennscott red clover did well after 11 weeks in tests on acid spoils overlaid with municipal sewage effluent and sludge (Sopper et al., 1974). White clover failed on sandy spoils in Ohio (Struthers, 1960).

Western Spoils

Alsike clover is well established on a southwestern Wyoming spoil banks after nine years, but needs periodic irrigation (May et al., 1971). White clover has done poorly on alkaline spoils in Montana (Thornburg, 1975). White clover has been grown on moist sites in upper subalpine regions of Colorado but has displayed poor vigor; red and alsike clovers displayed good vigor in the same regions, but where short-lived (Berg, 1975).

Alsike, red and white clovers are tolerant to salinity, alkalinity, and the presence of boron in the soil, but less so than white sweetclover (Hodgson et al., 1973).

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*See also sweetclover, listed separately.

Neebe, 1959; Limstrom and Merz, 1954). On calcareous spoils and lower slopes and alluvia [illegible]rowth obtained (Boyce and Neebe,1969). Intolera [illegible] not be planted with black locust (Ibid.). Poor or complete failure on acidic Illinois spoils (Ibid.).

Adaptable to dry site conditions of rocky Indiana spoils; good results on both calcareous sands and acid loams (Dietschman and Lane, 1952). Fifty-seven percent survival after 10 years; should not be underplanted with black locust (DenUyl, 1962).

Volunteered on moist bottom areas of Kansas spoils (Geyer, 1971). Good results on nutrient rich spoils at pH 5.6-6.1; better results from nursery plantings (Geyer and Rogers, 1972). Volunteers on Kansas, Missouri and Oklahoma spoils; does not tolerate intense competition (Clark, 1954).

Western Spoils

Poor results on Montana spoils under dry conditions; good on coarse spoils at pH 7.5-8.5 covered with topsoil (Thornburg, 1975).

Successful establishment and good growth on Iowa spoils; performance depends on exchangeable aluminum and soluble salt concentration, nitrogen and phosphorus deficiencies; 76 percent survival (Lorio and Gatherum, 1966; Lorio and Gatherum, Iowa Res. Bull. 535).

Mineral Tailings

Good growth in 12 years on Arizona copper tailings at pH 7.0-8.0 without irrigation or fertilizer (Miami Cu, 1972). Narrowleaf gave poor results on Climax mine tailings; not hardy enough (Brown, 1974).

CRABAPPLE: Malus sp.: Asian Crabapple - M. sp =1
Manchurian - M. bracteata

Tree. Slow growth rate on Pennsylvania and West Virginia spoils; nitrogen addition needed (Miles et al., 1973; Ruffner, 1966). Large numbers of crabapple species planted on various mine spoils with varying degrees of success (Ruffner, 1966). Asian gave poor results on Ohio spoils (Ruffner, 1965).

CREOSATE BUSH: *Larrea tridentata*

Evergreen shrub, year-round flowers, good windbreaker (Ludeke, 1973). Excellent on saline-alkaline tailings when watered and fertilized; will survive in shallow dry soils (Ludeke, 1974; *Ibid*.).

CROWNVETCH: *Coronilla varia*

Perennial flowering cool-season legume, which spreads both by seeds and rootstalks (Ruffner and Steiner, 1973). Several varieties are available commercially, notably Chemung, Emerald, and Penngift.

Eastern Spoils

Recommended for spoils with pH 5.5 or greater in Pennsylvania (Kendig, 1973; Miles *et al*., 1973), Kentucky (Carter *et al*., 1974; *Revegetation Manual*, 1966), and West Virginia (Ruffner, 1966), and on calcareous spoils banks in Ohio (Breeding, 1961; Parsons and Struthers, 1962). Should be seeded in the spring (*Revegetation Manual*, 1966). Chemung crownvetch is suggested for use throughout the Appalachian bituminous mining region; Emerald performs as well as Chemung in Kentucky, and Penngift is suitable for Pennsylvania and Ohio, but in its early growth is inferior to Chemung (Ruffner and Steiner, 1973). For acid spoils (pH less than 5.5) birdsfoot trefoil is a preferable legume (*Revegetation Manual*, 1966).

The establishment of a crownvetch cover may require two or three years, especially if seeding is used. Seeding crownvetch in combination with a quick cover crop may be advisable for erosion control. The *Revegetation Manual* (1966) suggests using weeping lovegrass for this purpose; Ruffner (1966) has used ryegrass; Ruffner and Hall (1962) suggest black locust and Kendig (1973) proposes hybrid poplar. An established cover of crownvetch may hurt the growth of tree seedlings (Carter *et al*., 1974).

Parsons and Struthers (196]) indicate that lime is the most important soil amendment for establishing crownvetch covers and note that the plants also respond to phosphorus. Ruffner (1966) found that the cover was not improved by fertilization as long as the soil pH exceeded 5.5.

Crownvetch was planted on limed anthracite breaker refuse in Pennsylvania, and survived at a rate of 90 percent after 2 years, but did not spread to a signficant extent (Czapowskyj et al., 1968). Liming was essential to survival, and mulching helped to a lesser extent; but fertilization had little effect (Ibid.).

Attempts were made to hydroseed crownvetch onto limed anthracite spoils and refuse banks. No growth was achieved on the refuse, and only fair survival was achieved on the northeast slopes of the spoils (Czapowskyj and Writer, 1970). Dickerson (1971) achieved good results planting crownvetch on acidic spoils overlaid with municipal sewage effluent and sludge. An attempt to grow crownvetch on a fertilized acid spoil neutralized with alkaline fly ash failed (Capp and Gillmore, 1974).

Midwestern and Western Spoils

Crowl (1962) recommends crownvetch for growth on steep banks in the Midwest with pH in the range 5.5-7.5. Crownvetch was planted in a subalpine region of Colorado, with poor results (Berg, 1975).

DATURA: Datura arborea

Evergreen shrub, large leaf and flower (Ludeke, 1973). Excellent results obtained on fertilized saline-alkaline tailings (Ludeke, 1974).

DEERTONGUE GRASS: Panicum clandestinum

Perennial grass native to eastern United States, so far used only for experimental plantings in Pennsylvania and West Virginia. Exceptionally acid-tolerant--grows on spoils with pH as low as 4.5 (Miles et al., 1973; Ruffner, 1966). Recommended for seedings in mixtures with switchgrass (McWilliams, 1971). Seedlings are weak, and cover is slow to develop (Ruffner, 1966). Considered second only to weeping lovegrass in its potential for revegetating anthracite refuse banks treated with municipal sewage effluent and sludge (Sopper et al., 1975).

DESERT BROOM: Baceharis sarothroides

Evergreen shrub, very adaptable, forms dense mat, 20-61 cm (8-24") high, 1.8 m (6') spread (Ludeke, 1973). Excellent results on fertilized Arizona saline-alkaline copper tailings; mixed with saltbrush, when fertilized (nitrogen and phosphorus added) (Ludeke, 1974).

DESERT ENCELIA: Encelia faunosa

Herb or sub-shrub, native to Utah and from California to Chile (Bailey, 1942). Rated excellent on saline-alkaline Arizona copper tailings with the addition of fertilizer (Ludeke, 1974).

DESERT TOBACCO: Nicotiana glauca

Grows as annual, reseeds profusely, grows on alkaline soils, slopes and rocky areas (Ludeke, 1973). Rated excellent on saline-alkaline Arizona copper tailings when fertilized (Ludeke, 1974).

DESERT WILLOW: Chilopis linearis

Deciduous shrub, grows 11 m (35') in one season, withstands cold and drought (Ludeke, 1973). Excellent results on fertilized saline-alkaline Arizona copper tailings (Ludeke, 1974).

DOGWOOD: Silky - Cornus amomum
Flowering - Cornus florida

Trees and shrubs, found usually under shade of taller trees in rich, well-drained soils (Sargent, 1933). Poor cover and stabilization on West Virginia spoils, inferior to autumn olive (Ruffner, 1966). Silky, very poor on acid spoils; good results on neutral spoils in Pennsylvania, West Virginia and Virginia (Ruffner, 1965).

DOUGLAS FIR: Pseudotsuga menziesii

Pyramidal trees, native to mountainous regions (Sargent, 1933; Cook et al., 1974). Frost sensitive and subject to needle cast (Rhabdocline) (Bureau of Mines, 1961). Should be restricted to sites with good soil and air drainage (Ibid.). Balsam fir suitable on coarse soils; may require fertilization; restrict to higher elevations and cool slopes (Ibid.). Douglas compatible with sod and annual plants (Bureau of Mines, 1961). Did not survive on elevations greater than 3000 m (10,000 ft) (Brown, 1974). Poor results in Pennsylvania (Hart and Byrnes, 1960). Survived on untreated iron ore tailings (pH 8.7) (Francis, 1964).

ELM: American (White Elm) - Ulmus Americana
Siberian - Celmus pumila

Tree with a tall trunk frequently buttressed at the base, found on river bottom-lands, intervales, low rich hills and stream banks (Sargent, 1933).

Siberian second to Russian olive in survival and growth on sloped sites (May *et al.*, 1971). Well adapted to growth on Wyoming spoils with pH 6.4, high clay, salt and organic material content and 23.93 cm (9.42 inches) of precipitation per year (*Ibid.*). Thornburg (1975) reports Siberian produced good results on coarse soils under dry conditions and on saline-alkaline spoils of Montana (pH 7.5-8.5) with 25-36 cm (10-14) inches) of precipitation per year. American elm volunteered on Kansas spoils (pH 6.0) (Geyer, 1971). Red elm is well adapted to loamy and clayey soils, especially calcareous banks (Limstrom and Merz, 1954). Can be planted in pure stands or in a mixture with black locust and other hardwoods; can be used in under planting (*Ibid.*).

EUCALYPTUS: Silver Dollar Gum - Eucalyptus polyanthenmos
Tiny Capsule - E. microtheca
Red Gum - E. rostrata

Mainly large trees, some shrubs; Silver Dollar Gum and Tiny Capsule are drought resistant; Red Gum is frost resistant, native to Australia and Malayan region (Bailey, 1942).

Rated fair to good on fertilized saline-alkaline Arizona tailings (Ludeke, 1974). Microtheca is strong growing, drought-tolerant and provides good stabilization (Ludeke, 1972). *Poly-anthemos* produced fast growth, good adaptation, excellent foliage (*Ibid.*).

FESCUE: Chewings - Festuca rubra var commutater
Hard, Sheep, Durar - F. ovina
Red - F. rubra
Tall - F. arundicea

Annuals or perennials (Hitchcock, 1935). Chewings is fine leaf, with a dense matted root system, best for well-drained sandy loams, usually combined with other grasses (Schellie and Rogier, 1963). Hodgson (1973) reports that Red tolerates ash with high pH and salinity in planting studies done on fly ash spoils in England. Red is a good cover on fertilized sites, but stands are short-lived (Ruffner, 1966). Flemining et al. (1974) reports that Fescue withstands low pH (4.0-5.0), excess manganese (4-64 ppm), but is less tolerant than lovegrass to aluminum deposits (2-12 ppm).

Tall fescue mixed with Ky 31 is persistent on slightly acidic spoils for at least 5 years; fertilizer is essential to establish (Ruffner, 1966).

Eastern Spoils

Tall grows well on West Virginia spoils at pH less than 6.0 when mixed with birdsfoot trefoil (Mellinger et al., 1966). Plass (1968) reports that Tall produced good results on spoils of pH 4.5-5.5. Trees planted in a two year growth of Tall did not hurt survival; however, growth of sycamores was limited; little effect on white or loblolly pine (Ibid.). More persistent than any cool season grass; provides good stands on limed soils; at pH 5.0, less than 20 percent cover in 3 years (Ruffner, 1966).

Struthers (1960) reports that fescues grow well on Ohio spoils but suffer from nitrogen deficiency. Tall and red fescue are recommended for plantings on Pennsylvania spoils; Red is not recommended for slopes of 25 percent or more (Guide for Revegetating..., 1965). Revegetation Manual (1966) reports that fescues may be seeded throughout the year in a mixture of lespedeza or birdsfoot trefoil and a quick cover species--ryegrass or weeping lovegrass (for spring seeding); Sudax, Pearl or Foxtail Millet or weeping lovegrass (summer seeding); ryegrass, rye or winter wheat (fall seeding); however, if erosion potential is a slight, a quick cover species may not be needed. Vogel and Berg (1968) observed that fescue did not produce well in Kentucky spoil reclamation without the addition of nitrogen; least tolerant to spoil toxicities associated with low pH. Mixtures containing a fescue did much better than those without. Some of the better mixtures are serecia lespedeza and crownvetch (Magnuson and Kimball, 1969). The mixture of creeping red fescue and serecia lespedeza had the highest ground cover percentage, averaging 45 percent (Ibid.).

Midwestern Spoils

Sorrell (1974) reports good results from the broadcast seeding of Kentucky fescue on Illinois spoils. Carter (1974) recommends tall and red fescue for Midwestern spoils with pH 4.0-5.5.

Mineral Tailings

Tall fescue produced 100 percent cover on northern Michigan iron ore tailings (pH 7.8-8.1) after 3 fertilizer applications; 30-40 percent cover obtained with only one application (Shetron and Duffek, 1970). Fair to poor results in plantings of tall fescue on moderate to coarse soils in Montana (pH 7.5-8.5); unsatisfactory results when planted on dry soil or steep slopes (Thornburg, 1975). Hard fescue gave moderate to weak seedling vigor in the subalpine regions of Colorado; subject to winterkill (Berg, 1975). Red fescue produced good results for upper subalpine regions in Colorado with long snow cover periods (*Ibid.*).

Merkel (1973) reports that Arizona fescue improved in density and vigor in regions of Colorado with 41.7 cm (16.4 inches) of precipitation per year (50 percent snowfall) and good soil; produced great amount of herbage. Good results obtained from a mixture of Ky 31 fescue, and perennial rye in a mixture with lespedeza and purple flowering vetch when hydroseeded and fertilized with paper pulp mulch and sulfur on Pennsylvania iron ore tailings (pH 8.9) (Francis, 1965). Czapowskyj and Writer (1970) report that tall fescue produced spotty ground cover on anthracite spoils and failed on breaker refuse even after hydroseeding and liming.

FLATPEA:

Climbing, herbaceous perennial legume (Hitchcock, 1935). Attractive flowers, good soil stabilizer, tolerates drought, thrives at pH 5.0; semi-evergreen in Southern Appalachians (Ruffner and Steiner, 1973).

Eastern Spoils

Grown successfully in West Virginia on spoils more acidic than pH 5.0 when fertilized with fly ash (Capp and Gillmore, 1974). Flatpea grows well in a mixture in Pennsylvania and is an excellent plant for wildlife (McWilliams, 1971). Good adaptation and vigorous growth; will grow in sandy soil and is acid-tolerant (Zak *et al.*, 1971; Miles *et al.*, 1973).

FOXTAIL GRASS: Creeping - Alopecurus arundinaceus
Meadow - A. pratensis

Annuals. Unsatisfactory results were found when planted in Pennsylvania bituminous spoils at pH 2.0-3.0 even when fertilized with sewage and sludge (Sopper et al., 1974). In Western subalpine regions only commercially available species to produce viable seed; fair to good vigor for meadow foxtail and fair to poor for creeping (Berg, 1975). Shows little promise as an adaptable species (Ruffner, 1966).

GOATSRUE (common): Tephrosia virgiana

Perennial herb. In West Virginia grows well on acid spoils when fertilized by fly ash (Capp and Gillmore, 1974). Fails on sandy soil (Zak et al., 1971).

GRAMMA: Blue - Bouteloua gracilis
Sideoats - B. curtipendula

Tufted, rhizomatous perennial or annual (Radford et al., 1968). Low growing grass, adapted to the Southwest desert areas, needs heavy seeding (Schellie and Rogier, 1973). Suggested for nothern Great Plains and northern New Mexico desert (Cook et al., 1974).

GREUSWOOD: Sarcobatus vermiculatus

Naturally occurring shrub, found in flat valley bottoms of high salinity (May et al., 1971; Cook et al., 1974). Recommended for dry saline-alkaline spoils in northern Great Plains and for desert areas in Arizona, Utah, Colorado and Wyoming (Cook et al., 1974).

HAZELNUT: Corylus americana

Shrub, 0.9-2.4 m (3-8 ft) high (called Filbert in Europe), grows well on moderately rich well-drained soil, subject to frost injury (Bailey, 1942). Susceptible to severe attacks of fungus disease (Cryptosporella anomala) (Ibid.). Fair to poor survival after 10 years on Pennsylvania bituminous spoils (Hart and Byrnes, 1960).

HEMLOCK: Tsuga carr.

Tall pyramidal trees (Sargent, 1933). Compatible with sod and annual plants (Bureau of Mines, 1961). Difficult to plant in open; use for underplanting or to hold cool moist sites (Bureau of Mines, 1961).

HONEYSUCKLE: Japanese - Lonicera japonica
Tatarian - L. tatarica
Amur -L. Maackii
Red - L. Zabelii

Shrub, palatable to wildlife; shows more vigor and adaptability as plants become mature (Ruffner and Steiner, 1973; Miles et al., 1973). Amur honeysuckle tolerates pH 5.0; adaptable throughout northeastern U.S. (Ruffner and Steiner, 1973). Amur is best suited for spoils over pH 5.5 and overlaid with limestone overburden (Miles et al., 1973). Less damage from deer and rabbits than autumn olive (Ibid.). Japanese honeysuckle provides food for wildlife, may climb wall and partially conceal it; susceptible to browse (McCart, 1973).

Eastern Spoils

Tatarian had 47.5 percent survival rate on spoils with pH 4.5 or greater in Pennsylvania (Magnuson and Kimball, 1969). Did not provide adequate cover (Ibid). Other species showed good vigor on spoils with pH greater than 5.0 and slopes 25 percent or less (Revegetation, 1965). Amur was slower to establish than autumn olive on bituminous spoils with pH 5.0 or greater (Ruffner, 1965). Tatarian produced very poor results on acid spoils and fair to good on moderately acid spoils in West Virginia and Pennsylvania (Ibid.). Carter et al. (1974) reported good results on Kentucky spoils with amur and tatarian at pH 4.5-7.5; good wildlife habitat.

Midwestern and Western Spoils

Bush honeysuckle produced good cover and wildlife food on Midwestern spoils at pH 4.5-7.0 (Crowl, 1962). Thornburg (1975) obtained good results on coarse, dry Montana spoils with pH 7.5-8.5 and 25-36 cm (10-14 inches) of precipitation per year. Poor results were obtained on wet, saline-alkaline soils (Ibid.).

HOPSEED BUSH: Dodonacea viscosa

Fast-growing multi-stemmed shrub; resistant to cold (Ludeke, 1973). Excellent results on fertilized saline-alkaline Arizona copper tailings (Ludeke, 1974).

INDIAN GRASS: Sorghastrum spp.

Coarse perennial (Hitchcock, 1935).

Eastern Spoils

Failed in West Virginia on acid spoils even when fertilized with fly ash plus another fertilizer (Capp and Gillmore, 1974). Ruffner (1962) reports that indian grass is adaptable on soutern West Virginia acid spoil banks. Evidence of spreading but original stand is not uniform. One of the better grasses; good stands have been produced on outer slopes by frost seedings. In Pennsylvania it is slow to become established, but shows good vigor and ability to reseed on spoils; can improve the ground cover (Miles et al., 1973). Cheyenne indian grass failed when planted on sandy soils (Zak et al., 1971).

INDIAN RICEGRASS: Oryzopsis hymmerroides

Perennial bunchgrass common to arid and semi-arid regions of the West (Hitchcock, 1935). Grows naturally in sand; survives on 3-18 cm (5-7") rainfall per year; clumps, trapping windblown seeds of other species; seeds prolifically; fixes nitrogen (Shirts et al., 1974). Difficult to germinate and treatments prescribed to reduce germination time include addition of sulfuric acid etch and hormone treatments (Ibid.).

Western Spoils

In Colorado, indian ricegrass establishes well with good stabilization (Merkel et al., 1973). Dean et. al. (1974) reports that encouraging results were obtained on Southwestern tailings. Poor germination rate on leached tailings of Utah copper mines (Nielson and Peterson, 1972).

Shirts et al. (1974) reports that it was found to be satisfactory in laboratory studies on tailings neutralized with limestone and sewage sludge. Satisfactory germination and survival was achieved on Washington copper tailings and Colorado uranium tailings (pH 2.7-3.5) after 15 weeks; poor results on highly saline Arizona copper tailings (Ibid.).

INDIGOBUSH: *Amorpha frutiscosa*: Mountain Indigo - *A. galbra*

Shrubby legume, grows 3-4.6 m (10-15'), acid-tolerant but prefers soils with pH 7.5-8.0 (Ruffner and Steiner, 1973). Open crown, sparse foliage, nonpalatable to livestock (*Ibid*.).

Eastern Midwestern Spoils

Adaptable over a wide range of acid mine spoils in West Virginia; provides little cover; good survival rate; heavy seed producer but does not spread rapidly by seeding (Ruffner, 1966). Mountain indigo produced poorly on acid spoils in West Virginia, good results on moderate to neutral spoils (Ruffner, 1965). Good results on Kentucky spoils with pH 4.5 or greater; hard to obtain commercially (*Revegetation Manual*, 1966). Ruffner (1965) reports that indigobush rated very good on Ohio spoils at pH 5.0; poor on Pennsylvania spoils at pH 4.0-5.0; good on spoils at pH 5.0; poor on Pennsylvania spoils at pH 4.0-5.0; good on spoils at pH 5.0 or greater; good on Virginia spoils at pH 5.0-7.0. Carter (1974) recommends indigobush for Midwestern acid spoils.

Mineral Tailings

False anvil indigo is slow to establish in tailing sands of Florida phosphate pits (Craig, 1975).

ISENBERG BUSH: *Melastoma malbathricum*

Trees, shrubs or herbs with watery juice, confined chiefly to the tropics and South America (Sargent, 1933). Plucknett (1961) reported rapid spreading on Hawaii bauxite spoils.

JACK PINE (also Scrub Pine, Gray Pine, Banks Pine): *Pinus banksiana*

A short-lived conifer native to the northern United States and Canada from the East Coast to the foothills of the Rocky Mountains (Fowells, 1965). Good initial growth, but slows up between 10 and 15 years (Wheeler, 1965). Outgrown by Virginia pine on anthracite spoils (Czapowskyk, 1970). Hardy species for infertile or frosty sites, but of poor form and subject to windthrow--should be used chiefly as a nurse for other species in adverse sites (Planting Sites..., 1961). Subject to injury by drought, and good only for pulpwood production (Wheeler, 1965). Subject to sawfly damage (Hart and Byrnes, 1960).

Eastern Spoils

Should grow satisfactorily at higher elevations, and will tolerate poor soils (Tryon et al., 1960). Red pine is preferable under these conditions, however (Ibid.).

Survival is highly dependent on pH, being best for acid spoils (Czapowskyj, 1970). Recommended for spoils with pH 5.0 or greater--provides good cover (Guide for Revegetating..., 1965). Survives on Pennsylvania acid spoils at pH 3.5 (Wheeler, 1965). Survival percentage was 89 percent on a plot with pH greater than 4.5, and 22 percent on another plot with pH less than 3.5 (Magnuson and Kimabll, 1969). Five year survival on Pennsylvania anthracite spoils at pH 4.0-7.0 (85 percent graded and 44 percent ungraded). Best conifer studied (Czapowskyj, 1970).

After 7 years on anthracite spoils, 74 percent survival at pH 4.0-4.5; 72 percent at pH 4.6-5.0; 55 percent at pH 4.1-5.5 and 34 percent for pH 6.1-6.5; best conifer studied for acid spoils (Czapowskyj and McQuilken, 1966). Performed well but less consistently than scotch pine (Davis and Melton, 1963).

Midwestern Spoils

Well adapted for planting on all sites except poorly drained bottoms and areas subject to flooding (Boyce and Neebe, 1959). Recommended for sands and loose loams or clays; needs good drainage (Crowl, 1962; Goldfinger, 1971; Limstrom, 1960; Limstrom and Merz, 1964). Successfully planted on clays and sands, and on acid and calcareous spoils (Boyce and Neebe, 1959).

On nutrient-rich spoil of pH 5.6-6.1 in Kansas, 19 percent survived after 22 years (less than shortleaf, Virginia and loblolly pines and cedars, greater than pitch pine), and the average height was 6.1 m (22 ft) (relatively low) (Geyer and Rogers, 1972). In Illinois on pH 5.0-6.0 spoils, 52 percent survived after 21 years (one of the best conifers), and the average height was 5.5 m (18 ft) on ungraded spoil and 4.0 m (13 ft) on graded spoil (relatively poor) (Chapman, 1967). In average survival and growth it was inferior to pitch pine on acid spoils, and inferior to red cedar and white cedar on mildly acid spoils (Lowry, 1960). It should not be planted with black locust or with any other species that will overtop it (Finn, 1958). Does best on south and west slopes; no serious disease, insect or rodent damage observed (Boyce and Neebe, 1959).

Mineral Tailings

Grew from 1.8-2.4 m (6 to 8') in 3 years on untreated refuse in Pennsylvania with pH 8.9 (Francis, 1965). Grew on tailings with pH 7.8-8.1 in northern Michigan, but was outgrown by red pine (Shetron and Duffek, 197). Fertilization appeared to have a negative effect on growth (*Ibid.*).

JAPANESE BLACK PINE: *Pinus thunbergii*

Trees or, rarely, shrubs (Sargent, 1933). Growth slows down after second and third years (Ruffner, 1966). Seems to be best pine for beach growth (Graetz, 1973). Francis (1964) reported that it survived on untreated iron ore tailings at pH 8.7.

JAPANESE FLEECEFLOWER (Knotweed): *Polygonum cuspidatum*

Large, robust perennial, dies back every year, provides much surface litter (Ruffner and Steiner, 1973). Belmont strain (Ky 795) grows and reproduces at pH 3.5; tolerates spoils as low as pH 3.2; adapts to spoils in Ohio, West Virginia and Kentucky (*Ibid.*). Miles *et al.* (1973) reports that the species grows rapidly, providing fair cover on Pennsylvania spoils. Established both vegetatively and by seed; rated very good on neutral spoils in Pennsylvania and West Virginia (Ruffner, 1965). Ruffner (1966) reported that adaptation is limited to a pH of 4.5 and above for plantings on West Virginia spoils and a pH of 5.0 for seeding on outerslopes of these spoils. Fair to poor results in 2 year test on acid West Virginia spoils with the addition of fly ash and fertilizer. *Revegetation Manual* (1965) reports good results on Kentucky spoils at pH 4.0 or greater, but hard to obtain commercially.

JUNIPER: Eastern - *Juniperus virginiana*
Chinese - *J. chinensis*
Shore - *J. conferta*
Savin - *J. sabina*

Pungent, aromatic trees or shrubs (Sargent, 1933). Savin and shore juniper are outstanding under adverse conditions (Dickens and Orr, 1969). Savin and Chinese juniper planted on several treated and untreated tailings in the West, showed growth on Washington copper and Colorado uranium tailings after 4 weeks; growth resulted on highly saline Arizona copper tailings only after treatment with sewage and sludge (Shirts *et al.*, 1974). Eastern juniper produced poor results of Wyoming tailings (May, 1971). Results obtained on Wyoming spoils with an average pH of 6.4, high clay, salt and organic plant content and 2.39 cm (9.42 inches) of precipitation per year (*Ibid.*). Thornburg (1975) reported that Rocky Mountain juniper produced good results on dry soils, pH 7.5-8.5, coarse soil covered with topsoil and 25-36 cm (10-14 inches) of precipitation per year. Creeping juniper gave fair to poor results except on moist non-saline spoils (*Ibid.*). Prostrate juniper produced good results at elevations greater than 3000 m (10,000 ft) (Brown, 1974).

KOCHIA: *Kochia scoparia*

Annual in polymorphous genus of shrubs, often woody at the base (Bailey, 1942). Best survival rate of all native plants on leached and nonleached Utah copper tailings (Nielson and Peterson, 1973). Twenty percent growth without leaching and 80 percent with leaching (*Ibid.*).

KUDZU: *Pueraria thunbergiana*

Trailing or climbing semi-woody vine (Radford *et al.*, 1968). Not to be planted near trees; useful for erosion control; good results on spoils with pH 5.5-7.5 (Crowl, 1962).

LARCH: Dunkfeld Hybrid - *Larix eurolepsis*
Japanese Larch - *L. japonica*, *L. leptolepis*
European - *L. decidua*

Tall pyramidal trees widely distributed over the northern and mountainous region of the Northern Hemisiphere (Sargent, 1933).

Eastern Spoils

Japanese larch is preferred to European larch on Northeastern spoils except on drier sites; Japanese grows as well or better elsewhere with less variation from tree to tree (U.S. Bureau of Mines, 1961). European is adaptable to medium fertility, moderate to good drainage; both European and Japanese are tolerant of late frost (U.S. Bureau of Mines, 1961). European is more drought-tolerant (*Ibid.*).

Eighty-two percent survival of Japanese larch on Pennsylvania spoils with initial pH above 4.5; 56 percent on spoils below pH 3.5 (Magnuson and Kimball, 1969). Larch usually provides more protective ground cover than most conifers because needle fall is greater and leaf litter accumulates more quickly; growth is reduced on leveled or compacted soils (Miles et al., 1973). Davis and Melton (1963) reported that Japanese grew well on graded and ungraded spoils; European performed poorly on most banks and did not perform as well as Japanese. Both Japanese and European produced good cover, although hard to establish on Pennsylvania bituminous spoils with pH above 5.0 and slopes 25 percent or less. Japanese reported to be fastest growing conifer (Guide for Revegetating..., 1965; Wheeler, 1965). Forty-two percent survival after 10 years, 3.75 m (12.3 ft) height on graded spoils, 6.34 m (20.8 ft) height on ungraded spoils--for Japanese larch. Good results on upper slopes, spoils with low soil content (Hart and Byrnes, 1960). Fifty percent survival after 5 years on Pennsylvania anthracite spoils at pH 4.0-7.0 for a graded spoil; 44 percent for ungraded (Czapowskyj, 1970). Japanese had best all-round survival rate on Pennsylvania anthracite spoils (68 percent average, 1.8 m (5.9 ft) in height) after 7 years; European was hurt by acidity and helped by grading (Czapowskyj and McQuilken, 1966).

European and Japanese larch are hard to establish on West Virginia spoils (Ruffner, 1966). Ruffner (1966) does not recommend this species for planting on spoil sites in the State. European subject to frost injury; suggested for plantings at elevations below 1200 m (4,000 ft); requires soils which are moist with good drainage (USBM, Circular 109, 1960). Japanese expected to be important in future as it will tolerate unfavorable spoil conditions (Ibid.). Rapid growth on West Virginia spoils, but nonuniform (Ruffner, 1966; Brown, 1971).

Compatible with annual plants and with the thinner or more open types of sod for Allegheny plantings; susceptible to damage from frost, rabbit clipping and deer browsing (U.S. Bureau of Mines, 1961).

European should be planted in pure stands on Ohio spoils; will grow well in northern part of State on relatively moist sites containing coarse textured materials (Finn, 1958).

LESPEDEZA: Kobe - *Lespedeza striata*
Korean - *L. stipulacea*
Bicolor - *L. bicolor*
Sericea - *L. cuneata*
Chinese - *L. cuneata*
Natob - *L. bicolor natob*
Japanese - *L. japonica*
Thunberg - *L. thungergii*

Annual or perennial (Hitchcock, 1935). Japanese is a small shrub, 1.8-2.4 m (6-8 ft); most stems die back in winter; exists only as far north as Long Island (Ruffner and Steiner, 1973). Sericea used widely but often establishes slowly (Vogel, 1964). Responds well on spoils above pH 5.0 when nitrogen and phosphorus are added (*Ibid.*). Sericea best all-round lespedeza; grows well on drained loose soils of Mississippi, Tennessee and Kentucky and the red soils of the Piedmont; reasonable on sandy loams (Guernsey, 1970). Best results obtained on spoils with pH 6.0-6.5, but grows on spoils with pH 4.0-7.0; plant early spring with fertilizer and lime (*Ibid.*). Good mixed with fescue (*Ibid.*).

Eastern Spoils

Sopper *et al.* (1974) report that lespedeza grows well after 11 weeks on spoils with pH 2.0-3.0 when fertilized with municipal sewage effluent and sludge. Sericea will grow on refuse banks covered with clay but not fertilized or limed (Bureau of Mines, 1973). Ruffner (1966) reports that Natob is the only lespedeza to produce in West Virginia mountains. Good survival on spoils above pH 4.5; not effective for erosion control; poor results on steep slopes where pH is 5.3 or higher (*Ibid.*). Sericea has also proved to be good cover on West Virginia acid spoils; useful for mine spoil revegetation (*Ibid.*).

Sericea produced adequate results on northeastern slopes of Pennsylvania anthracite spoils after hydroseeding and liming (Czapowskyj and Writer, 1970). No survival on ungraded breaker refuse; better than crownvetch on other ungraded sites (*Ibid.*). Korean lespedeza is less tolerant than fescue to adverse conditions of mine refuse; used in treatment plots; needs lime and fertilizer for good establishment (Davidson, 1974). Can be established from plants and by direct seeding; not effective as ground cover; best for Pennsylvania spoils with pH 4.5 (Miles *et al.*, 1973). Chinese lespedeza produces good ground cover on moderately acid spoils of low fertility (Ibid.). Magnuson and Kimball (1969) report average survival with natob lespedeza on pH 4.5 spoils; 66.5 percent survival typical.

Sericea is widely used to revegetate Kentucky spoils and other disturbed areas but establishes slowly, doesn't respond to phosphorus in spoils above pH 5.0 but has good response with the addition of nitrogen (Vogel, 1964). Can also be established with weeping lovegrass (Ibid.). Korean and Kobe reseed themselves every year and provide quick cover; Kobe is more acid tolerant (Revegetation, 1966). Carter et al. (1974) recommends a mixture of Sericea and Ky 31 plus various quick cover species, 2.2 g/m^2 (20 lbs per acre) for all year planting on Kentucky spoils; Korean and/or Kobe, 0.6 g/m^2 (5 lbs per acre) for early spring planting. Bicolor and Japanese produced well for winter food and wildlife habitat on spoils with pH 4.5-7.0 (Ibid.). Sericea is inferior to birdsfoot trefoil at higher altitudes (Ibid.). Bicolor and Thunberg produce best results on spoils with pH 5.0 or greater; nitrogen fixers (Revegetation Manual, 1965).

Struthers (1960) reports that Sericea and Korean are very useful since they supplement seeding mixture when other plants fail on spoils in Ohio. Hill (1968) reported that Sericea stands were erratic in some areas and outstanding in others on Ohio spoils.

Midwestern Spoils

Carter et al. (1974) recommends Sericea as the best legume for acidic Midwestern spoils, and Japanese and Bicolor as best shrubs. Chinese lespedeza produces profuse cover for wildlife on spoils with pH 4.5-6.5 (Crowl, 1962). Korean produces good forage on pH 4.5-6.5; Bicolor and Japanese produce good food and cover on spoils with pH 4.5-7.5 (Ibid.).

LIVE OAK: Quercus virginniana

Tree (Sargent, 1933). Promising for dune areas, along with Eastern red cedar (Graetz, 1973). Direct planting of acorns has produced good results (Ibid.).

LOBLOLLY PINE: Pinus taeda

Tree with a tall, straight trunk (Sargent, 1933). Better growth than shortleaf, Virginia or pitch pine after 6 months in laboratory tests on sandstone and shale soils, 51 cm (20") (pH 3.5); 56 cm (22") (pH 3.9); 60 cm (23.5") (pH 6.6); 30 cm, (12") (pH 7.6). Grew one year on kaolin spoils in Georgia; needed nitrogen and phosphorus.

Eastern Spoils

Failed to establish a stand when planted on Pennsylvania spoils (Miles et al., 1973). Ruffner (1966) reported rapid growth after seven years in plantings on West Virginia spoils. May prove to be a valuable species in the warmer sections of the State; only limited test plantings as yet recommended (U.S. Bureau of Mines, Circular 109, 1960).

Best form among the pines in western Kentucky plantings; best results on ridges and upper slopes, planted on moderately acid to acid spoils (pH 6.5-4.5) (Boyce and Merz, 1948). Fast growth, desirable timber species, may suffer snow damage (Revegetation Manual, 1966; Carter et al., 1974). Sixty-seven percent germination at temperatures from 30°-50°C; 41 percent at 60°C; and 15 percent at 65°C (Revegetation, 1965). Forty-six percent survival, 2.7 m (8.8 ft) in pure stands; 3.1 m (10.2 ft) in mixtures with European alder, after 5 years on ungraded, silty clay shale spoils in eastern Kentucky at pH 3.5-5.5 (Dale, 1963). Thirty percent survival after 4 years on sandstone and shale spoils at pH 4.5-5.5 (Plass, 1968).

Preferred species for plantings in Tennessee and Alabama; erratic performance in pure stands; good results in mixtures with Virginia pine (Zarger, Curry and Allen, 1973). Fifty-five to seventy-five percent survival of planted trees on slopes at pH 4.1-5.3 (silty clay loam, variable fertility) after 3 years in the Tennessee-Cumberland spoils; better growth with a southern exposure (Thor and Kring, 1964). Planted trees survived better than seeded (Ibid.).

Faster growth than shortleaf or Virginia during first 5 to 10 years in plantings in Southern States; 65 percent survival, good ground cover (Plass and Burton, 1967).

Generally reported to be compatible with annual plants on Allegheny spoils; very compatible with light brush (U.S. Bureau of Mines, 1961).

Midwestern Spoils

Fast growing, good form on Midwestern spoils at pH 4.0-7.5; recommended for plantings on sands or loose loams and clays (Crowl, 1962; Limstrom, 1960).

Suitable for plantings in sparse stands of sweetclover on Illinois spoils; unsuitable for underplanting or mixed plantings; killed in northern Illinois by freezing (Boyce and Neebe, 1959). Fastest growing pine planted on acidic spoils (pH 4.5-6.9) of southern Illinois; best results on well drained bottoms and lower slopes (Ibid.).

Forty-two percent survival on spoils in Kansas, Missouri and Oklahoma after 6 years (Clark, 1954). Sixty-eight percent survival on ungraded Illinois spoils after 21 years (pH 5.0, rocky soil); 83 percent survival, 15 m (50 ft) height, on Kansas and Missouri spoils that were ungraded; grading cuts survival to 30 percent (Illinois) and 6 percent (Kansas-Missouri) respectively (Chapman, 1967).

Twenty-two percent survival, 6.1 m (22 ft) height after 22 years on Kansas spoils at pH 5.6-6.1; promising results (Geyer and Rogers, 1972; Geyer, 1971).

LONGLEAF PINE: Pinus palustris

A tree with a tall, straight, slightly tapering trunk (Sargent, 1933). Generally reported to be compatible with sod and annual plants; a conifer that may be browsed by deer (Bureau of Mines, 1961). Good growth reported, although difficult to plant in relation to other pines (Plass and Burton, 1967). Fourteen percent survival on spoils with pH 4.0 or better; very important in strip mine afforestation (Ibid.). Good prospect for pulpwood production (Ibid.).

MAPLE: Red - Acer rubrum
Silver - Acer saccharinum
Sugar - Acer saccharum

Trees or, rarely, shrubs; widely distributed over the Northern Hemisphere (Sargent, 1933).

Eastern Spoils

Red volunteers on Pennsylvania bituminous and West Virginia spoils (Medve, 1974; Brown, 1960). Red is most tolerant of species tested (Sturn, 1973). Sugar produced the best growth and survival rate when grown in a mixture with black locust on lower slopes and well drained bottom lands of Kentucky spoils (Merz and Boyce, 1948). Silver adapted to strip mined spoils in Ohio, but shows fastest growth on moist soils (Finn, 1958). Tendency toward multiple sprouting (Ibid.). Silver produced good results on Ohio spoils with coarse or loose soils at pH 4.0-8.0 (Carter et al., 1974). A nurse species aids growth; should not be planted on upper slopes (Ibid.).

Midwestern Spoils

Plant silver maple on upper and lower slopes with pH 6.0-7.5 in a 0-25 percent mixture with black locust and on sands and loose or compact loams and clays (Limstrom, 1960). Sugar maple should be planted on lower slopes (pH 6.0-7.5) in a 25-50 percent mixture with other hardwoods on loose or compact loams and clays (Ibid.). Crowl (1962) reported that silver and sugar also produced good results on Midwestern spoils with pH 4.0-8.0, in a 25 percent mixture with black locust (silver) and in a mixture with other hardwoods (sugar).

Silver is adaptable to all Illinois spoils having a high proportion of soil; should be planted in a hardwood mixture or for underplanting on decadent black locust stands (Limstrom and Merz, 1954; Boyce and Neebe, 1959). Slow growth, but high survival rates--59 percent on northern Illinois spoils, less than 43 percent on southern Illinois spoils (Ibid.). After 21 years on spoils with pH 5.0-6.0, 40 percent soil content, silver had a 46 percent survival rate, 12 m (40 ft) height on ungraded spoils and a 10 percent survival, 5.5 m (18 ft) height on graded spoils (Chapman, 1967).

DenUyl (1962) does not recommend silver or red maple for plantings on Indiana spoils--50 percent survival after 10 years. Deitschman and Lane (1952) reported good results, however, with silver maple planted on calcareous loams and silty shales of Indiana spoils when underplanted with decadent black locust.

MATRIMONY VINE (Box-Thorn): *Lycium sp.*

Deciduous or evergreen shrub, with or without thorns (Bailey, 1942). Good on dry, coarse, saline-alkaline soils with pH 7.5-8.5 when covered with topsoil in Montana (25-36 cm (10-14 inches) of precipitation per year (Thornburg, 1075)).

MESQUITE: *Prosopis*: Chilean - *Prosopis chilensis*
Native or Honey Locust - *P. juliflora*

Trees or shrubs, found from southern Kansas to Patagonia and tropical Africa, southwestern and tropical Asia (Sargent, 1933). Produces hard durable wood, valuable as fuel; pods are used as fodder (*Ibid.*).

Mineral Tailings

Native and Chilean mesquite produced excellent results on saline-alkaline Arizona copper tailings (Ludeke, 1974). Honey showed good adaptation and excellent stabilization on alkaline spoils; grew 9.1-12 m (30-40 ft) (Ludeke, 1972). Chilean can withstand insect damage to an extent, excellent adaptation, grew to 9.1 m (30 ft) (*Ibid.*).

MILLET GRASS: Foxtail - *Sintaria italica*
Pearl - *Pennisetum galucum*

Annual. Foxtail is cultivated in warmer parts of U.S. especially Nebraska to Texas (Hitchcock, 1935). Pearl cultivated to limited extent in South (*Ibid.*). Used as temporary cover on spoils with pH 4.5 or greater in Kentucky (*Revegetation Manual*, 1966). Carter (1974) recommends pearl or German millet mixed with Ky 31 and Sericea for late spring planting, 1.1 g/m^2 (10 lbs/acre).

MICROSCOPIC PLANTS (Algae, Lichens, Mosses)

Dean *et al*. (1974) reports that these plants failed in saline copper tailings in the Southwest. Worked to some extent on uranium and other less saline copper tailings; promising for arid regions with low salinity (*Ibid.*).

MUGHO PINE (Mountain Pine): *Pinus Mugo mughus*

Shrub or tree, about 4.6 m (15 ft) tall, in mountains of central and southeastern Europe (Chittendon, 1956). Only specie to perform well on West Virginia spoils below pH 4.5, and slopes at 25 percent angle or less; slow growth rate; acid tolerant (Ruffner, 1966; *Revegetation*, 1965). Miles *et al*. (1973) reported good results on Pennsylvania spoils at pH 4.0-4.5; cover produced is attractive for wildlife purposes.

MYRTLE (Downy and Indian Gooseberry): *Rhodomyrtus tomentosa*

Trees or shrubs abounding in pungent aromatic volatile oil, with minute scaly buds (Sargent, 1933). Grows rapidly on Hawaii bauxite spoils (Plucknett, 1961).

NARROWLEAF TREFOIL: *Lotus tenuis*

Herbs and legume (Bailey, 1942). Establishes well on spoils above pH 5.0 and responds well to fertilizer; semi-prostrate growth habit, non-rhizomatous; cover is inferior to crownvetch (Ruffner, 1966). Best adapted to northern Pennsylvania; fertilizer is required only on spoils of high lime content and on north or east exposures (Miles *et al*., 1973). On Allegheny spoils, exceptional for production of vigorous stands; appears as pasture plant on dry shallow soils; good adaptation to strip mine spoils (Ruffner, 1962).

NEEDLEGRASS: *Stipa avenacea*

Perennial, grows in dry or rocky open woods (Hitchcock, 1935). Tresler (1975) reports green needlegrass, native species in Wyoming, is good for loams and heavier soils with precipitation greater than 33 cm (13") per year.

NORTHERN BAYBERRY: *Myrica pennylsvania*

Aromatic resinous trees and shrubs, with watery juice, terete branches and small scaly buds (Sargent, 1933). Promising shrub for dune areas (Graetz, 1973).

OAK: White - *Quercus alba*
Red - *Q. borealis*, *Q. rubra*
Chestnut - *Q. montana*
Bur - *Q. macrrocarpa*
Sawtooth - *Q. acutissima*

Trees or shrubs with astringent properties (Sargent, 1933). Inhabits temperate regions of the Northern Hemisphere and high altitudes in the tropics, southward to the mountains of Colombia and to the Indian Archipelago (*Ibid.*).

Eastern Spoils

Sawtooth oak produced poorly as a soil stabilizer (Ruffner and Steiner, 1966). Good results obtained on moist, fertile, slightly acidic spoils of Virginia, Kentucky and central and southern West Virginia (*Ibid.*). Magnuson and Kimball (1969) reported an average survival rate of 42.5 percent for sawtooth oak on Pennsylvania spoils with pH above 4.5, but inadequate cover production.

Red oak has a slow growth rate for the first few years, good survival rate and adaptability--better on graded (pH 5.0 or greater, slopes 25 percent or less) than ungraded Pennsylvania spoils (Miles *et al.*, 1973; *Revegetation*, 1965; Davis and Melton, 1963). Wheeler (1965) reported oak to be more adversely affected by grading of Pennsylvania bituminous spoils than other species. Hart and Byrnes (1960) reported red to be best for highly acidic Pennsylvania spoils (pH 3.2, 29 percent survival after 10 years) followed by pitch pine (23 percent) and red pine (21 percent); little litter or ground vegetation. Better growth on lower slopes and sheltered areas (*Ibid.*).

Bur oak produced good results on the upper and lower slopes of Midwestern spoils at pH 5.0-6.0 in a 0-25 percent mixture on sand and loose or compact loams and clays (Limstrom, 1960). Good results on Kansas spoils at pH 7.5 (loose, shaly clay) (Seidel and Brinkman, 1962). Transplants survived better than seedlings on nutrient-rich Kansas spoils at pH 5.6-6.1--27 percent survival after 22 years, 8.5 m (28 ft) height, tolerates heavy herbaceous competion (Geyer and Rogers, 1972; Clark, 1954). Seeds produced 72 percent survival (pH 5.5-7.0, 63 percent soil), 11 m (35 ft) height after 20 years, on Kansas and Missouri ungraded spoils; 16 percent survival, 6.1 m (20 ft) height on graded spoils (Chapman, 1967).

OATGRASS: Tall - Arrhenatherum elatius

Perennial, good stands on fertilized acidic spoils, some evidence of spreading, stands not persistent at any one place (Ruffner, 1966).

Eastern Spoils

Fails on sandy soils (Zak *et al*., 1971). Shows better vigor and cover first year than tall fescue, decreases on lime spoils (Ruffner, 1966). Shows good adaptation on spoils in Pennsylvania; recommended species for spoils with pH 4.5 or greater (Miles *et al*., 1973; *Guide for Revegetating*..., 1965). Ruffner (1962) recommends tall oatgrass on spoil banks and shallow shale soils; adapts to moderately acid spoils of low fertility.

OLIVE: Autumn - Elaeagnus umbellata
Russian - E. anguistifolia

Shrub. "Cardinal" autumn olive is a nitrogen-fixing, non-leguminous shrub, multiple-stemmed, grows 4.6-6.1 m (15-20 ft) on good sites (Ruffner and Steiner, 1965). Next best species to black locust for quick stabilization (*Ibid*.). Russian is tolerant of high pH and salinity (Hodgson *et al*., 1973). Widely adaptable and useful over a longer period of time than most shrubs (Ruffner, 1965).

Eastern Spoils

Autumn produced good cover and yielded heavy fruit on Pennsylvania spoils at pH 4.5 or greater, 54.5 percent survival (Magnuson and Kimball, 1969; Davis, 1973). Russina gave poor results on Pennsylvania bituminous spoils; autumn poor on hignly toxic bituminous spoiles, but good results on spoils with pH 5.0 or greater (Ruffner, 1965).

Autumn olive adapted to variable sites and climatic conditions of West Virginia spoils; heavy fruit production; nitrogen fixing (Ruffner, 1966; Brown, 1971). Russian did not survive on spoils below pH 4.0 (Ruffner, 1966). Autumn olive provides erosion control and wildlife habitats on Kentucky spoils at pH 4.0-7.5 (Carter *et* al., 1974; *Revegetation Manual*, 1965). Autumn olive produced good results on acidic Ohio spoils and fair results on moderately acidic spoils (Ruffner, 1965).

Midwestern and Western Spoils

Russian rated good on Illinois bituminous spoils (Ruffner, 1965). Autumn tolerates pH 3.0-4.0 on Illinois and Indiana spoils (*Ibid.*). Autumn is one of several highly adaptable shrubs recommended for Midwestern spoils (Carter et al., 1974). Russian olive produced best survival and greatest growth rate on wyoming spoils, average pH 6.4, high clay, salt and organic content, average rainfall, 2.39 cm (9.42 inches) per year (May *et* al., 1971).

Mineral Tailings

South African olive produced good adaptation and stabilization on Arizona copper tailings; good resistance to insects (Ludeke, 1977). Native olive produced good growth on alkaline tailings; good adaptation but fertilizer is needed (*Ibid.*). Thornburg (1975) reported good results for Russian olive on all Montana tailings at pH 7.5-8.5 when covered with topsoil and receiving 25-36 cm (10-14 inches) of precipitation per year.

ORCHARDGRASS: *Dactylis glomerta*

Perennial, introduced forage grass (Radford, 1968). Stands difficult to establish without prepared seedbed; density not outstanding (Ruffner, 1966).

Eastern Spoils

Grows on mine spoils with pH 2.0-3.0 when treated with 5 cm (2") sewage effluent and 5 cm (2") sludge (Dickerson, 1971). Mellinger *et al.* (1966) suggests that orchardgrass be mixed with alfalfa for spoils with pH greater than 6.0. In Ohio it was mixed with birdsfoot trefoil; this proved not as successful as the alfalfa mixture which took over from the birdsfoot trefoil (Krause, 1964). Grows well on Pennsylvania spoils with pH 5.0 or greater, on non-stony soil and slopes less than 25 percent (*Guide for Revegetating*..., 1965). Struthers (1964) rates orchardgrass as the principal grass for Southeast Ohio soils; rated both for stand and vigor in spring seeding.

Midwestern and Western Spoils

Use in mixture on Midwestern spoils with pH 6.0-8.0; hardy growth results (Shirts *et al.*, 1974). On Western spoils, good for high altitude plantings (Eamon, 1974).

Mineral Tailings

Shetron and Duffek (1970) recommend orchardgrass for northern Michigan iron mine tailings with pH 7.8-8.1, after fertilization. Dean *et al.* (1971) reports promising results on mine tailings in the Southwest. Poor results obtained on Washington copper tailings (pH 2.6-3.5, 978 m (3209 ft) altitude, 76 cm (30") rainfall per year), even after addition of fertilizer, lime and sewage sludge; brome, tall fescue and wheatgrass fared better in this area (Shirts *et al.*, 1974).

OSAGE - ORANGE: *Maclura pomifera*

Tree with stout, erect spreading branches forming open irregular round-topped head (Sargent, 1933). Found in rich bottom lands, southern Arkansas to southern Oklahoma and south to Texas (*Ibid.*). Most abundant and largest in size in the Red River Valley in Oklahoma (*Ibid.*). Used in Kansas, Missouri, and Oklahoma as fenceposts (Clark, 1954). Recommended for planting on sands or loose loams and clays, at pH 4.5-8.0; will also grow on compact loams and clay (Limstrom, 1960; Crowl, 1962). Suitable for planting in dense stands on upper slopes and ridges and for underplanting in decadent black locust stands on Illinois spoils (Boyce and Neebe, 1959). Survival rate 33-67 percent on well drained spoils of pH 4.5 or greater. (*Ibid.*). Does well on most strip mined spoils in Ohio, either in pure stands or in mixture with black locust (Finn, 1958).

PANDAGRASS (mixture with Intortim)

Grows on bauxite strip spoils, needs extensive fertilization (Younge, 1961).

PANICGRASS: *Panicum amarum*

Deep-rooted, long-lived coastal warm season perennial (Radford, 1968). Adaptable from Massachusetts to North Carolina (*Ibid.*). Good on very sandy, droughty sites, graded and ungraded sand and gravel, sand dunes (Ruffner and Steiner, 1973). No viable seeds; only wild rootstalk can be transplanted (Graetz, 1973). Gave fair response on West Virginia spoils even though fertilized with fly ash plus another fertilizer (Capp and Gillmore, 1974).

PERU PEPPER

Tree or shrub usually found in the tropics (Bailey, 1942). Very rapid growth, 4.6-7.6 m (15-25 ft) on Arizona copper tailings; tolerant of alkaline spoils; especially useful for desert tailings (Ludeke, 1972).

PITCH PINE: *Pinus rigida*

Tree with a short trunk (Sargent, 1933).

Eastern Spoils

Good results produced on coarse soils at low elevations or warm sites, suitable for deep dry sites and as nurse or cover on other adverse sites (U.S. Bureau of Mines, 1961). Lorio and Gatherum (1966) reported 76 percent survival related to cation exchange capacity, nitrifiable nitrogen and soluble salt concentration. Recommended for sands and clays (*Ibid.*).

Good survival on Pennsylvania bituminous spoils at pH greater than 5.0 and slopes 25 percent or less (*Guide for Revegetating*...., 1965)--36 percent survival after 10 years on Pennsylvania spoils; tolerates acidity; abundant litter but killed by pine sawfly (Hart and Byrnes, 1960). Czapowskyj (1970) reported a 76 percent survival rate on graded anthracite spoils (pH 4.0-7.0) after 5 years; 28 percent for ungraded. Fair survival but poor vigor (Miles *et al.*, 1973).

Dale (1963) reported a 90 percent survival on ungraded, silty, clay shale, Kentucky spoils (pH 3.5-5.5). Excellent results on western Kentucky spoils of pH 6.5-4.5 (Boyce and Merz, 1948; Carter et al., 1974). Reported to be generally compatible with annual plants (U.S. Bureau of Mines, 1961).

Grows slowly and is commonly rough in appearance on West Virginia spoils; survives on shallow, dry soils which are low in fertility; will tolerate a high pH; recommended for use on adverse sites (USBM, Circular 109, 1960). Germination occurred soon after seeding; (Brown, 1973).

After 6 months, Plass (1960) reported good results in laboratory tests on sandstone and shale soils; grew 43 cm (17") for pH 3.5-6.6 (less than loblolly, equal to shortleaf and greater than Virginia) and 28 cm (11") at pH 7.6.

Lowry (1960) reported good survival and growth on strongly acidic Ohio spoils, both sandy and silty clay soils. Well adapted to upper slopes as well as sandy and loamy spoils; plant in pure stands or in group mixtures with other conifers (Limstrom and Merz, 1954). Should not be planted with black locust or other species that will overtop it; will grow on relatively dry ridges of Ohio spoils; fastest growth on lower slopes (Finn, 1968).

Midwestern Spoils

Recommended for sands or loose loams and clays at pH 4.0-7.5; resists tipmoth but often has poor form (Crowl, 1962; Limstrom, 1960). Should not be planted in forest plantings because of poor form and growth; successfully planted on all sites except poorly drained areas in Illinois (Boyce and Neebe, 1959). Forty percent survival after 21 years on Illinois spoils of pH 5.0-6.0, 40 percent soil content (Chapman, 1967).

Fourteen percent survival on nutrient-rich Kansas spoils after 22 years at pH 5.6-6.1 (only Ponderosa pine fared worse).

PONDEROSA PINE: Pinus ponderosa

Tree found on mountain slopes, dry valleys and high mesas from northwestern Nebraska and western Texas to the shores of the Pacific Ocean and from southern British Columbia to lower California and northern Mexico (Sargent, 1933).

Eastern and Midwestern Spoils

Inferior growth to pitch pine on strongly acid spoils, and to cedars on neutral spoils (Lowry, 1960). Average survival and growth after 2 years on Ohio acidic spoils with sandy loams or silty clays (*Ibid.*). Geyer and Rogers (1972) reported 3 percent survival after 22 years on nutrient rich Kansas spoils of pH 5.6-6.1, 7.6 m (25 ft) average height. Rated poor in all respects after 10 years on Pennsylvania bituminous spoils (Hart and Byrnes, 1960). Fifteen percent survival after 6 years on Missouri and Oklahoma spoils, particularly susceptible to needle-cast fungus (Clark, 1954). Fair results on Montana spoils (pH 7.5-8.5) when overlaid with topsoil and receiving 25-36 cm (10-14 inches) of precipitation per year (Thornburg, 1975).

POPLAR: White - *Populus alba*
Yellow or Tulip - *Liriodendron tulipifera*

Large fast growing trees (Sargent, 1933). White is tolerant of high pH and salinity in fly ash spoils in England (Hodgson et al., 1973). Good results from interplantings with European black alder in Germany (Knabe, 1964).

Eastern Spoils

Hybrid popular and other hardwoods are worth planting only on better sites of Northeast spoils, with adequate preparation and protection. Poplar should be restricted to moderate and well drained sites with moderate to high fertility (U.S. Bureau of Mines, 1961).

Seems to be vulnerable to frost damage and rabbit clipping in plantings on Allegheny spoils (U.S. Bureau of Mines, 1961).

Fifty percent survival on pH 3.0-5.0; should be good on gravel pits in Pennsylvania (Jones, 1973). Eastern shows little promise; planted seedlings inferior to volunteer plants (Miles et al., 1973). Hybrid showed good growth at pH 4.5 or greater and slopes 25 percent or less; should not be planted with larch (*Revegetation*, 1965). Forty-five percent survival after 10 years, 9.4 m (31 ft) average height on Pennsylvania spoils; susceptible to canker; provides sparse litter; has good form and forms closed canopy (Hart and Byrnes, 1960). Seventy-seven percent survival on graded spoils; 55 percent, ungraded on Pennsylvania anthracite spoils (pH 4.0-7.0) after 5 years (Czapowskyj, 1970).

Yellow poplar volunteers on West Virginia spoils (Brown, 1960). Curly poplar produced good stands, becomes multiple-stemmed and bushy without maintenance (Ruffner, 1966). Clones NE-41, 46, 47, 49, 50, 51 and 53 all produced good results on West Virginia spoils (Eschner, 1960). Trimble (1963) reported good results with hybrid clones on high altitude, stony spoils in West Virginia (limed and unlimed surfaces); 20 percent survival on unlimed spoils after 3 years, 80 percent on limed; 0.9 m (3 ft) height on unlimed surfaces after 10 years, 1.2 m (4 ft) on limed. Highest survival rate on West Virginia spoils was 80.3 percent; did not do well on strip mined spoils (Brown, 1962). Yellow volunteers on West Virginia spoils (Brown, 1960).

Sixty-eight percent survival in pure stands after 5 years for yellow poplar on eastern Kentucky ungraded spoils (pH 3.5-5.5, silty clay shale); 50 percent in mixtures with European alder (Dale, 1963). Yellow poplar does best on well drained bottoms and in mixtures with black locust on spoils in western Kentucky; slow growth, poor form (Boyce and Merz, 1948).

Yellow poplar has erratic survival on Ohio spoils (Hill, 1968). Yellow adapted to loamy and clayey banks in protected locations; best results when pH is 5.5-8.0; should be planted on bottoms or lower slopes or in mixtures with black locust (Limstrom and Merz, 1954). Hybrid is suitable for planting on most strip mined land in Ohio; survives well and grows rapidly (Finn, 1958). Yellow should only be planted on lower slopes and banks composed of loamy and well drained clayey materials; should not be planted on very acid banks (*Ibid.*). Tulip should only be planted on lower slopes of ungraded spoil banks; nurse species aids growth (Carter *et al.*, 1974). Sixty-eight percent survival on unfertilized Ohio spoils (pH 5.0-7.0, loose, shaly soil) after 2 years; 36 percent on fertilized spoils (Funk and Krause, 1965). Grading hurts survival and growth of yellow poplar (Limstrom, 1964).

QUACK GRASS: *Agropyron repens*

Dense, rhizomatous perennial common to fields, waste places and roadsides in the Southeast (Radford, 1968). Poor results on sandy soils (Zak *et al.*, 1971). Failed to germinate on leached tailings in the West (Nielson and Peterson, 1972).

RABBITBRUSH: Big - *Chrysothamnus nanseousus*
Little - *C. viscidiflorus*

Low branching shrub, matures rapidly and furnishes browse; nutritious (McArthur et al., 1974). Very useful for erosion control and recommended for desert areas in the West (*Ibid*, Cook et al., 1974). Ludeke (1974) reported excellent results on saline-alkaline Arizona copper tailings. Volunteers on Wyoming tailings and looks promising in other areas (May et al., 1971; Dean *et al.*, 1971).

REDBUD: *Cercis canadensis*

Tree or shrub found in the eastern and western parts of North American, southern Europe, and southwestern, central and eastern Asia (Sargent, 1933). Good survival and vigor on moderately acid spoils in Illinois, but very poor results on Pennsylvania spoils (Ruffner, 1965).

RED PINE: *Pinus resinosa*

Tree with a tall straight trunk, usually on light sandy loams or dry rocky ridges (Sargent, 1933).

Eastern Spoils

Good growth on Pennsylvania spoils under severe conditions when mixed with lovegrass, fescue and lespedeza (Walter, 1974). Survival was better on spoils treated with lime and fertilizer (Ibid.). Severely damaged where European pine shoot moth was prevalent (Davis and Melton, 1963). Effective species for revegetating disturbed lands and good adaptability (Aharrah and Hartman, 1973). Forty-nine percent survival (less than Scotch pine, better than other conifers), 2.1 m (7 ft) height (less than jack, Scotch, pitch pine or Japanese larch) after 10 years on Pennsylvania bituminous spoils (Hart and Byrnes, 1960). *Guide for Revegetating* (1965) reports good results and adaptation on bituminous spoils with pH 5.0 or greater and slopes 25 percent or less. Sopper et al. (1975) reported good survival along with Austrian and white pine in laboratory tests on anthracite spoils at pH 3.0. Eighty percent survival after 5 years on graded anthracite spoils of pH 4.0-7.0; 36 percent survival on ungraded spoils (Czapowskyj, 1960). Czapowskyj and Writer (1970) reported failure on limed and hydroseeded graded Pennsylvania spoil and breaker refuse.

Good results obtained in forestation of West Virginia gob piles with pH below 3.5 in a mixture with birch (Coalgate, 1973). Best adapted to higher elevations, 760 m (2500 ft), tolerant of low nutrient and moisture soil, and drought, suited to unfertile, dry areas (Bown, 1971; USBM, Circular 109, 1960; Ruffner, 1966). Grows well for 10-15 years then declines in warm areas; 70.6 percent survival on West Virginia spoils (Brown, 1962).

Herbaceous ground cover and foliage coloration have positive effect on red pine with use of fertilizer on New York spoils (Kirkland, Jr., 1952). Good growth on upper slopes and well drained sandy and loamy soils or Ohio spoils (LImstrom and Merz, 1954). Plant in pure stands or mixtures with other conifers (*Ibid.*). Poor results on loose shaly soil of pH 5.0-7.0 in Ohio; 8 percent survival, 20 cm (8") height after 2 years (Funk and Krause, 1965).

Midwestern Spoils

Good results on soils with pH 4.0-7.5, subject to tipmoth (Crowl, 1962). Recommended for sands and loose loams and clays (Limstrom, 1960). Stopped planting in Indiana in 1963 (Medvick, 1973).

Mineral Tailings

Good results on northern Michigan iron ore tailings with dark, very fertile sands; good for reforestation (Goldfinger, 1971). Out survived jack pine and black locust after 2 years on Michigan iron ore tailings with pH 7.8-8.1.

REDTOP: *Agrotis alba*

Cool season, medium-lived grass. Thrives almost everywhere--most spoils, shallow ponds, well drained, infertile soils, acid spoils (pH 4.5-7.5); forms dense sod, binds against erosion (McWilliams and Wallace, 1973; Carter *et al.*, 1974). Invades, good as temporary cover mixed with Kentucky bluegrass, lasts 2-3 years, less competitive than ryegrass; grows best in northeastern United States (Bramble and Ashley, 1955; Schellie and Rogier, 1963).

Eastern and Midwestern Spoils

Struthers (1960) recommends that redtop be added to mixtures as it quickly spreads into bare spots. Grows on acid spoils in Pennsylvania with pH 4.5 or greater and on slopes of less than 25 percent angle (*Guide for Revegetating*..., 1965). Grows on Midwestern spoils with 5.0-6.0; very successful in ravines in mixtures (Crowl, 1962).

Mineral Tailings

Used as part of a mixture for stabilizing gold mine tailings in South Africa (Stabilizimg Mine Dumps, 1968).

REED CANARYGRASS: *Phalaris arundinacea*

Rhizomatous perennial, common to low woods and stream banks (Radford, 1968). Failed on sandy soils (Zak et al., 1971). Good results obtained on Pennsylvania bituminous spoils with pH 5.0 or greater, and on steep, non-stony slopes and soils (*Guide for Revegetating*..., 1965). will also grow on toxic soils (pH 2.0-3.0) when fertilized with 5 cm (2") sewage effluent and 5 cm (2") sludge per week--good results (Sopper et al., 1974). Carter et al. (1974) recommends reed canarygrass for Midwestern acid spoils in a mixture with fescue and switchgrass. Grows on moist sites but hard to establish on subalpine spoils (Berg, 1975).

RHODESGRASS: *Chloris gayana*

Promising meadow grass in irrigated regions (Hitchcock, 1935). Preferable to bermudagrass when rainfall is less than 64 cm (25") per year; recommended for southwestern United States (Schellie and Rogier, 1963).

ROSE: Multiflora - *Rosa multiflora*

Deciduous shrub with vigorous, long, recurving or climbing branches (Bailey, 1942). Good results obtained on soils with pH 4.5 or greater and slopes 25 percent or less (*Revegetation*, 1965). Fair to poor results on West Virginia spoils at pH greater than 5.0 (Ruffner, 1965). Good results obtained on Indiana spoils and very good results on Ohio spoils with pH 4.5-6.5; some cases of unwanted spreading. Wildrose produced good results on coarse dry spoils in Montana with pH 7.5-8.5, overlaid with topsoil and 25-36 cm (10-14 inches) of precipitation per year (Thornburg, 1975).

ROSE ACACIA: *Robina hispida*

Trees or shrubs (Sargent, 1933). Often confused with bristly locust--acacia is smaller and generally sterile (McWilliams, 1970).

RUBY SHEEPBUSH: *Enchylaena tomentosa*

Evergreen shrub, hardy on alkaline soils, tolerates spoils with high salt content (Ludeke, 1973).

RUSSIAN THISTLE: *Salsola kali*

Annual (May *et al.*, 1971). Volunteered on younger Wyoming spoil banks--primary pioneer species (*Ibid.*). Sixty-nine percent survival on leached Utah copper tailings, second only to kochia (Nielson and Peterson, 1973). Volunteered on fertilized Nevada copper tailings, 2000 m (6500 ft) altitude in areas with 21 cm (8.3 inches) of precipitation per year.

RYE: Balboa, Winter - *Secale cereale*
Russian Wild Rye - *Elymus junicias*

Annual.

Eastern Spoils

Russian wild rye failed on West Virginia acid spoils although fertilized with fly ash plus another fertilizer (Capp and Gillmore, 1973). In Kentucky Balboa grows on spoils with pH 4.5 or greater; recommended for early spring or late summer plantings, 7.8 g/m^2 (70 lbs per acre) in a mixture with Ky 31 and sericea. Quick cover in winter--more competitive than wheat with permanent species (*Revegetation Manual*, 1966). *Revegetation* (1966) reports that rye is one of the best species for high germination in a mixture with tall fescue, weeping lovegrass, and hybrid sorghum.

Mineral Tailings

Fair growth observed on saline copper mine waste when pelletized and sewage sludge added (Dean and Havens, 1973). Shirts *et al.* (1974) report that plantings were tried on Nevada copper tailings at 2000 m (6500 ft) in an area with 21 cm (8.3") rainfall per year; when mixed with alfalfa and clover, fertilized and Coherex added--overall survival 12 percent after 1 month. Russian wild rye survived and did well at same altitude in Nevada on tailings with pH 7.5 and rainfall 13-25 cm (5-10") per year (Shirts *et al.*, 1975). Fair to poor in Montana on coarse spoils plus topsoil with pH 7.5-8.5 (Thornburg, 1975). Merkel *et al.* (1973) observed that Balboa wild rye gave good stands in Colorado in comparison to wheatgrass in areas of 41.7 cm (16.4 inches) rainfall and 50 percent snow; not adequate to prevent erosion, however. Russian wild rye produced a good stand under the same conditions on tailigns with pH 8.4. Salina wild rye made only fair progress under identical rainfall and snowfall conditions, but it is probably best suited for erosion control (*Ibid.*).

RYEGRASS: Annual - *Colium multiflorum*
Perennial - *Lolium perenne*

Short-lived cool season perennials and annuals (Radford, 1968; Hitchchck, 1935; Carter *et al.*, 1974). Perennial does well on fertilized sites but decreases rapidly after first year; tolerant to high pH and salinity (Hodgson, 1973; Ruffner, 1966). Schellie and Rogier (1963) report that ryegrass can be good for 3-4 years, best on fertile moist soils.

Eastern and Midwestern Spoils

Annual responds to fertilizer and provides quick cover on sites as low as pH 5.0 in West Virginia; failed on unfertilized mine spoils (Ruffner, 1966). Grew on Kentucky spoils covered with clay and then seeded (U.S. Bureau of Mines, 1973). Either is recommended for spring planting on Kentucky mine spoils, 1.1 g/m^2 (10 lbs per acre) in a mixture of Ky 31, lespedezas; annual may also be used for summer planting in mixture with Ky 31 and sericea on spoils with pH 4.5 or greater. Carter *et al.* (1974) observed good growth in Midwestern laboratory studies on very acid soils treated with lime and sewage sludge. On Midwestern spoils, Crowl (1962) observed quick cover on spoils with pH 6.0-7.0.

Mineral Tailings

Germinated on leached cooper and uranium tailings (pH 7.0) (nielson and Peterson, 1972). Czapowskyj and Writer (1970) observed no survival of perennials on breaker refuse of anthracite spoils and negligible growth on graded spoils. Francis (1965) recommends ryegrass for Pennsylvania iron ore tailings with pH 8.9, when hydroseeded with paper pulp mulch, sulfur, fertilizer and in a mixture with Ky 31, lespedeza and purple flowering vetch. Annual ryegrass gives quick cover for winter growing season on Arizona copper tailings; high growth, good stabilization, but less cover than winter barley (Ludeke, 1974).

SAGEBRUSH: Big Sagebrush - *Artemisia tridentata*

Shrub, grows up to 3.7 m (12 ft), mostly in the Northern Hemisphere and most abundant in arid regions (Bailey, 1942).

Big sagebrush is rich in protein in the winter when other plants are low in nutrients (McArthur *et al.*, 1974). Rapid growth, exceptional reproduction, establishes well when included in aerial seeded mixtures of herbs; good vigor and cover (*Ibid.*). Other species of big sagebrush are effective soil stabilizers as well as range species (*Ibid.*). Big sagebrush volunteers on Wyoming spoils (May *et al.*, 1971). Ludeke (1974) reported that big sagebrush produced good results on saline-alkaline Arizona copper tailings.

Grassland sagebrush has good suitability and moderately good availability for rehabilitation (Farmer *et al.*, 1974). Sagebrush steppe dominates in open grassland containing wheatgrasses and needle and thread on silt to silty clay loam soils (*Ibid.*). Occurs chiefly in northeastern Wyoming; good suitability and availability for rehabilitation (*Ibid.*).

European sage produced good results on leached Utah copper mine tailings (Nielson and Peterson, 1972).

SAINFOIN: *Onobrychis viciaefolia*

Tolerant legume, but less tolerant than sweetclover (Hodgson *et al.*, 1973).

SALTBUSH: Nutall - *Atriplex nutallii*
Three Wing - *A. canescens*
Four Wing - *A. canescens*
Cut Bush - *A. vesicarum*
Quail Bush - *A. lentiformis*
Australian - *A. semibaccata*
Old Man - *A. nummuloria*

Shrub, native to the Southewast, drought tolerant (Ludeke, 1974). Produces good results on saline-alkaline Arizona copper tailings when fertilized with 22 g/m^2 (200 lbs, 1 acre) nitrogen, 5.6 g/m^2 (100 lbs, 1 acre) phosphorus and 11 g/m^2 (50 lbs, 1 acre) of potassium (*Ibid.*). Four wing and three wing and old man saltbrush provide good cover; Old Man should be cut less than three or four wing (*Ibid.*). Poor results obtained from Quail Bush and Austrailian (*Ibid.*). Used in range restoration and soil stabilization; high forage yield and wide adaptation (McArthur and Giunta, 1974).

Ludeke (1973) reported that four wing tolerates high alkalinity and is fire resistant; quail bush tolerates salinity. Good results obtained with four wing on dry coarse Montana spoils, covered with topsoil (pH 7.5-8.5) and receiving 25-36 cm (10-14 inches) precipitation per year (Thornburg, 1975). Poor results obtained on wet soils (Ibid.). Low (12 percent) germination rate for four wing on leached Utah copper tailings, no germination on non-leached tailings (Nielson and Peterson, 1973). Four wing produced good results on loam and sandy soils, (0.1 g/m^2 (1 lb seed per acre)) of Wyoming spoils in areas with less than 41 cm (16 inches) of precipitation per year (Tresler, 1975). Springfield (1970) suggests heavy seeding for good germination results for four wing.

SALT GRASS: *Distichlis stricta*

Perennial. Failed to germinate when planted on Utah copper tailings (Nielson and Peterson, 1972).

SAND DROPSEED: *Sporobalus cryptandium*

Perennial, usually in small tufts (Hitchcock, 1935). Found everywhere but in the southeast (*Ibid.*). Recommended for desert areas throughout Southwest and north to Colorado sandhills (Cook et al., 1974). Beverly (1970) reports that it grew in one summer on Colorado uranium tailings.

SASSAFRAS: *Sassafras albidum*

Aromatic trees found in the uplands of western New England to the mountains of western North Carolina and eastern Tennessee (Sargent, 1933). Volunteers on West Virginia spoils (Mellinger et al., 1966).

SCOTCH BROOM: *Cytisus scoparius*

Most acid tolerant shrub tested (horn and Ward, 1969). Valuable for wildlife forage and cover plant on Midwest spoils (Crowl, 1962). Best results reported on spoils with pH 4.0-7.5 (*Ibid.*). Ruffner (1965) reported good results in Ohio on spoils with pH 4.5-7.5. Unable to withstand winters in Pennsylvania and West Virginia (*Ibid.*).

SCOTCH PINE: *Pinus sylvestras*

Tree, widely distributed through the Northern Hemisphere (Sargent, 1933). Planted as ornamental and Christmas trees (*Ibid.*; USBM, Circular 109, 1960; Brown, 1971; Crowl, 1962).

Eastern Spoils

Hardy species for dry and infertile sites; select seed origins with good winter color and other characteristics; prefer phosphorus where suitable; foliage may discolor on coarser soils (U.S. Bureau of Mines, 1961). Not recommended for timber production in Pennsylvania because of low production value (*Ibid.*). Eighty percent survival after 10 years on bituminous Pennsylvania spoils, 2.6 m (8.4 ft) height (Hart and Byrnes, 1960). Produces well on spoils with pH 5.0 or greater and on slopes 25 percent or less (*Guide for Revegetating*..., 1965). Failed on Pennsylvania anthracite breaker refuse even with hydroseeding and liming; poor emergence but good growth on graded spoils (Czapowskyj and Writer, 1970). Seventy-four percent survival, 1.3 m (24 ft) height after 5 years on graded anthracite spoils; 42 percent on ungraded (Czapowskyj, 1970).

Brown (1962) reported 65.8 percent survival on West Virginia spoils at pH 4.0 and above--less than black locust, red and white pine, European larch or yellow poplar. Less vigor than Virginia and shortleaf pine, same as red and more than white (Mellinger *et al.*, 1966). Nutrient and moisture requirements are low for West Virginia plantings; growth and survival good; origins from central Europe best for pulpwood production (Brown, 1971). Reported to be compatible with annual plants (U.S. Bureau of Mines, 1961). Mouse girdling specifically reported in West Virginia (*Ibid.*). Stands deterioriate at early age (USBM, Circular 109, 1960).

Slow growth on Kentucky spoils for the first few years; good results on spoils at pH 4.0-7.5 (Carter *et al.*, 1974; *Revegetation Manual* 1966). Good results on New York spoils with the addition of fertilizer (Kirkland, Jr., 1974).

Midwestern and Western Spoils

Planting recommended for sands and loose loams and clays at pH 4.5-6.0 (Limstrom, 1960). Good results obtained at pH 4.0-7.5 on Midwestern spoils (Crowl, 1962).

Fair results on coarse Montana spoils at pH 7.5-8.5, overlaid with topsoil, in areas of 25-36 cm (10-14 inches) of precipitation per year; poor results on saline-alkaline soils (Thornburg, 1975).

Mineral Tailings

Good results on northern Michigan tailings in light colored sand (Goldfinger, 1971).

SCOURING RUSH: *Equisetum hyemale*

Weed, found usually in moist or swale-like places (Bailey, 1942). Most conspicuous volunteer on northern Michigan copper tailings (Erbisch, 1975).

SEA OATS: *Uniola paniculata*

Coarse, rhizomatous perennial (Radford, 1968). Predominates from Virginia to Texas, found on beaches, takes over from American Beachgrass (Woodhouse *et al.*, 1968; Graetz, 1973). Good replacement for beachgrass in pioneer zone plantings; persists after soil is stabilized; slow to start; interplanting is recommended with beachgrass for quick cover (*Ibid*). Woodhouse *et al.* (1968) recommend nursery germination then transplantation--hard to transplant wild sea oats; nitrogen and phosphorus are good additives, but can grow without them. Deep planting of established growth is key (Graetz, 1973).

SHADESCALE: *Atriplex confertifolia*

Shrub, native to Wyoming and uplands of Colorado (May *et al.*, 1971; Cook *et al.*, 1974). Recommended for desert areas in Utah, Colorado, Wyoming and Montana (Cook *et al.*, 1974).

SHEEP SORREL (also Sour Grass): Rumex acetosella

Root sprouting perennial (Radford, 1968). Failed in Pennsylvania plantings (Miles *et al*., 1973). Ruffner (1966) reports that emergence on West Virginia spoils was poor until second or third year. Produces a better cover than most grasses on low fertility sites; averaged 25 to 30 percent on spoils between pH 4.5-5.0 (*Ibid*.).

SHORTLEAF PINE: Pinus echinata

Tree with tall tapering trunk found throughout the United States (Sargent, 1933).

Eastern Spoils

Sixty percent stand in Pennsylvania when seeded on pH 4.5 spoils (Miles *et al*., 1973). Sixty-six percent survival and good growth--11 m (37 ft) from plantings on southern spoils (Plass and Burton, 1967). Plass (1969) reported fair to good results in laboratory studies on sandstone and shale spoils after 6 months: 41 cm (16"), (pH 3.5); 43 cm (17"), (pH 3.9); 53 cm (21"), (pH 6.6); 36 cm (14"), (pH 7.6).

Best initial vigor of pines studied on West Virginia spoils; vigor improving, canopy not closed (Mellinger *et al*, 1966; Ruffner, 1966). Fifty-one and one-half percent surival on West Virginia spoils (less than European larch, yellow poplar, red spruce, black locust, red and white pine, Scotch pine, Norway and red spruce) (Brown, 1962). Good for plantings on eroded and dry sites at elevations of 300 m-460 m (1,000 to 1,500 ft) or less; susceptible to winterkill; mouse girdling a specific problem (Brown, 1971; Bureau of Mines, 1961). Should be planted in warmer sections of State on well drained spoils (USBM, Circular 109, 1960).

After 5 years, 74 percent survival on ungraded, silty clay shale of Kentucky spoils of pH 3.5-5.5; 2.4 m (7.9 ft) average height planted in pure stands, 2.8 m (9.2 ft) in mixtures with European alder (Dale, 1963). Good results at pH 4.0-7.5 (Carter *et al*., 1974).

Six percent survival on Ohio spoils at pH 5.0-7.0 (loose, shaly soil; worst tree but best conifer) (Funk and Krause, 1965; Lowry, 1960). In Ohio it should be planted only in the southeast (Carter *et al*., 1974). Limited generally to spoil banks; do not plant on calcaceous spoils; otherwise site requirements and recommendations are as for jack pine

(Limstrom and Merz, 1954). Best results on moderately acid sites in Ohio, adaptable to variety of spoils, should not be planted with black locust or other species that would overtop it (Finn, 1958).

Midwestern Spoils

Good results on spoils at pH 4.0-7.5; survival often affected by drought (Crowl, 1962). Recommended for sands or loose loams and clays (Limstrom, 1960). Stopped planting in Indiana in 1957 (Medvick, 1973).

Best results on southern Illinois spoils (pH 4.5-5.9); more resistant to storm damage than loblolly, heavily infested with tipmoth (Boyce and Neebe, 1959). Chapman (1967) reported 35 percent survival on spoils (pH 5.0) in Illinois after 21 years; 68 percent in Kansas and Missouri (pH 5.0-7.0). Twenty-nine percent survival on nutrient rich spoils, pH 5.6-6.1, in Kansas after 22 years; a recommended species (Geyer and Rogers, 1972).

Mineral Tailings

Survived on untreated Pennsylvania iron ore tailings at pH 8.7 (Francis, 1974).

SILKY DOGWOOD: Cornus obliqua or Cornus amomum

Shrub, recommended for spoils with pH greater than 4.5 (Revegetation Manual, 1966). Good survival on slopes with a 25 percent angle or less, except on very acidic spoils (Revegetation, 1965; Hart and Byrnes, 1960). Survival rate less than black chokeberry on highly toxic spoils in Pennsylvania (Hart and Byrnes, 1960).

SORGHUM GRASS: Sorghum spp.: Milo-maize - Sorghum vulgare
Sudangrass - S. sudanense

Coarse perennial or annual (Radford, 1968). Sudangrass (annual) provides temporary crop for erosion control; killed by frost; should be seeded with perennial (Schellie and Rogier, 1963).

Eastern Spoils

Sudax (hybrid of Sudangrass and Sorghum) good for temporary cover on Kentucky spoils, germinates with fertilizer (Revegetation, 1966; Revegetation Manual, 1966). Best germination at low temperatures (30-40°C); 90 percent successful at 60°C, outgrows almost everything, will germinate at higher temperatures mixed with weeping lovegrass, tall fescue or rye (Revegetation, 1966). Carter et al. (1974) suggests a mixture of Sudax with Ky 31 ($2.2\ g/m^2$) (20 lbs per acre) for late spring planting. May poison livestock (Revegetation Manual, 1966).

Mineral Tailings

Younge (1961) reports that sudangrass grows on Hawaii baxuite tailings but only after the addition of a great deal of fertilizer. Sudan and milo-maize have extremely quick germination during summer growing season on Arizona copper tailings (Ludeke, 1974). Milo-maize provides good stabilization, food and cover for wildlife (Ibid.). Morgan and Parks (1967) report that grain sorghum and sudangrass did well on Tennessee phosphate spoils with pH 5.3 but both needed nitrogen and lime additives. Sudangrass also needed potassium additives (Ibid.).

SPANISH PINE: Pinus Pinaster

Tree, successfully cultivated in central and southern California (Sargent, 1933). Stands planted on West Virginia spoils are decreasing slightly (Ruffner, 1966).

SPRUCE: Red - Picea rubens
Norway - P. abies
White - P. glauca
Englemann - P. engelmannii

Pyramidal trees, with tall tapering trunks, often stoutly buttressed (Sargent, 1933).

Eastern and Midwestern Spoils

Red spruce seems to grow on any soil with a surface or raw humus layer; only fair results on acid sites (U.S. Bureau of Mines, 1961). Black is resistant to frost, infertility, poor drainage; good for cover but not timber production; white, tolerant of poor drainage and high lime, sensitive to low fertility, more suitable for Christmas tree production (Ibid.). Norway is preferred to white because of faster growth; affected by white pine weevil, frost, fertility and very poor drainage; should be planted at higher elevations (Ibid.). Norway is shade tolerant, but takes many years to provide suitable cover (Wheeler, 1965). White rated poor for growth on Pennsylvania bituminous spoils (Hart and Byrnes, 1970).

Ninety-four percent survival of Norway spruce on Pennsylvania spoils with pH above 4.5; 27 percent on spoils below pH 3.5 (Magnuson and Kimball, 1969). Fifty-two percent surival of Norway and white spruces after 7 years on anthracite spoils at pH 5.1-5.5; better results on ungraded spoils (Czapowskyj and McQuilken, 1966). Czapowskyj (1970) reported 41 percent survival on graded anthracite spoils (pH 4.0-7.0) and 20 percent on ungraded after 5 years; 36 percent on graded and 25 percent on ungraded for White. Norway and white spruce produced good results on spoils at pH 2.0-3.0 when overlaid with 5 cm (2") municipal sewage effluent (Dickerson, 1971).

Red spruce outperformed hybrid poplars on acid spoils in West Virginia plantings (Trimble, 1963). Norway and red had 59.1 percent and 63.2 percent survival rates respectively on West Virginia spoils; grows very slowly the first 6 or 7 years, needs protection (Brown, 1962). Brown (1971) reported that Norway spruce has very high water and nutrient requirements; survival and growth on West Virginia spoils is fair. Norway is good for Christmas tree production; moist well drained soil is preferred for West Virginia spoils; heavy clays, eroded and dry sites should be avoided (USBM, Circular 109, 1960). Red spruce grows well only where the soil is moist; should be planted in colder sections of the State; desirable timber species but susceptible to damage by spruce budworm and fire (Ibid.).

Reported to be compatible with annual plants on spoils in the Allegheny regions; Norway and white area also compatible with light brush (Bureau of Mines, 1961).

Crowl (1962) reports good results with Norway spruce on Midwestern spoils at pH 5.0-6.0; good Christmas tree production.

Mineral Tailings

Brown (1974) reported good results with Englemann on high altitude mineral tailings, poor results with blue spruce.

SUDANGRASS: (see Sorghum sudanense)

SUMAC (Sumach): Smooth - Rhus glabia
Skunkbush - R. trilobata
Shining - R. copallina
Fragrant - R. raromatica

Tree with colorless water juice (Sargent, 1933). Found on dry hillsides and ridges from northern New England to eastern Kentucky, Tennessee and southern Florida, southeastern Iowa, Nebraska, Kansas and the San Antonio Valley, Texas (Ibid.).

Eastern and Midwestern Spoils

Good results on acid, low fertility spoils; provides little cover (Ruffner, 1966; Miles et al., 1973). Good survival on spoils with pH 4.0; fragrant is not acid tolerant (Ruffner, 1966). Flameleaf produces well on acid, low fertility spoils; adaptable to pyritic and limestone spoils in Pennsylvania (Miles et al, 1973). Shining and smooth produced good results on spoils with pH 4.0-5.5; poor results below pH 4.0; poor cover producing plants (Ruffner, 1965; Revegetation Manual, 1965). Brown (1960) reported that skunkbush volunteers on West Virginia spoils.

Smooth produces good results on Midwestern spoils with pH 5.0-6.5; good as late winter bird food, deer browse (Crowl, 1962).

Mineral Tailings

Not adaptable for revegetation of Wyoming spoils; poor results in all locations (Lang, 1971). Average Wyoming spoil had pH 6.4, high clay, salt and organic material content and 2.39 cm (9.42 inches) of precipitation per year (Ibid.). Skunkbush gave good results on all Montana spoils (coarse, dry, saline-alkaline, pH 7.5-8.5) when overlaid with topsoil. These Montana spoils typical receive 25-36 cm (10-14 inches) of precipitation per year (Thornburg, 1975)

SWEETGUM: *Liquidambar styraciflua*

A tree with balsamic juices (Sargent, 1933).

Eastern Spoils

Showed little promise when planted on Pennsylvania spoils but established a 60 percent stand when seeded on pH 4.5 spoils (Miles *et al.*, 1973). No vigor, poor stands on West Virginia spoils below pH 5.0; better stands at lower elevations (1966).

Ninety percent survival, 0.6-0.9 m (2-3 ft) height on sandstone and shale of Kentucky spoils of pH 4.5-5.5 (Plass, 1968). After 5 years 67 percent, 2 m (6.7 ft) height on ungraded silty clay shale spoils of pH 3.5-5.5 when planted in pure stands; 47 percent, 2.7 m (8.7 ft) height in stands mixed with European alder (Dale, 1973). Plant in bands or blocks on Kentucky and Ohio spoils at pH 4.5-7.5; nurse species aids growth; do not plant on upper slopes with loose or coarse soils (Carter *et al.*, 1974).

Midwestern Spoils

Good results on sands and loose or compact loams and clays in 0-25 percent mixture, pH 4.5-7.5 (Limstrom, 1960; Crowl, 1962).

Seventy percent survival after 21 years on silty clay ungraded Illinois spoils (40 percent soil, pH 5.0-6.0), 19 m (63 ft) height; 45 percent survival, 10 m (33 ft) height on graded spoils (Chapman, 1967). Can be planted under black locust and shortleaf pine on neutral Illinois spoils; average height 4.3-5.5 m (14-18 ft) after 16 years--less than black walnut, yellow poplar and silver maple. Good growth on lower slopes and bottoms where pH was more than 5.5 (Boyce and Neebe, 1959). Suitable for planting in areas with flooding either as pure plantings or in a mixture with silver maple, ash, and black locust (*Ibid.*; Limstrom and Merz, 1954). Survival less than 20 percent in northern Illinois where species was damaged by ice (Boyce and Neebe, 1959). Adapted to clay and to loamy and sandy soils having a reasonably high percentage of soil; susceptible to rabbit damage (Limstrom and Merz, 1954). Fifty-five percent survival after 10 years on Indiana soils; good results on moderately acidic spoils (DenUyl, 1962).

SWITCHGRASS: Panicum virgatum

Annual or perennial, usually in large clumps (Hitchcock, 1935). Tall, robust warm season perennial with short rhizomes (Ruffner and Steiner, 1973). Easy to establish on soils with pH 5.5 or greater; persistent stands, good stabilizing cover (Ibid.). Black switchgrass is good for all Northeastern spoils; Carthage best for coastal plains (Ibid.). Will establish on tailing sands (Craig, 1975).

Eastern and Midwestern Spoils

Good results obtained with Blackwell on Pennsylvania spoils at pH 2.0-3.0, when overlaid with 5 cm (2 inches) sewage effluent and 5 cm (2inches) sludge per week for 11 weeks (Sopper et al., 1974). Failed on sandy soils (Zak et al., 1971). Guide for Revegetating... (1965) reports good results on neutral spoils and steep slopes. Drought tolerant and adaptable to Pennsylvania spoils with low fertility; stands usually better than bluestem or indiangrass (Miles et al., 1973; Williams, 1970). Cover established in tree planting on mine spoils (Williams, 1970). Good results produced on high lime spoils even when too steep or stony for using normal agricultural practices; desirable grass for wildlife food and cover (Ruffner, 1962). Blocks erosion and holds refuse in place on Pennsylvania spoils; produces substantial cover; germination and survival percentage good; proper grading and terracing necessary to maintain (Smith, 1972; Schimp, 1966).

Blackwell and Carthage produced good results on West Virginia acid spoils with the addition of fertilizer and fly ash (Capp and Gillmore, 1974). Best growth on spoils at pH 6.0; good stands established by seeding without fertilizer; good cover and erosion control (Ruffner, 1966).

Good results on Kentucky spoils at pH 4.5-8.0; provides habitat and food for wildlife; tolerates less abuse than Ky 31 (Carter et al., 1974; Revegetation Manual, 1966). Kanlow and Blackwell switchgrass are recommended in mixtures with rye, and sericea or birdsfoot trefoil (Revegetation Manual, 1966). Vogel and Berg (1968) reported good results on very acid Kentucky spoils but required 2 years to establish. In less acidic spoils switchgrass yields herbage on top and roots about equal to lovegrass yields (Ibid.).

Carter et al., (1974) recommends switchgrass for acidic Midwestern spoils in a mixture with fescue and reed canarygrass.

SYCAMORE: Platanus occidentalis

Tree found on the borders of streams and lakes on rich bottomlands of the Midwest, northeastern and southern United States (Sargent, 1933).

Eastern Spoils

Does not exhibit the vigor or rapid growth on Pennsylvania spoils usually common to volunteering plants (Miles et al., 1974). Eighty percent survival, rapid growth but little vigor on West Virginia spoils; volunteers, provides little cover (Ruffner, 1966; Mellinger et al., 1966; Brown, 1960). Grazing sycamore produced good results (Ruffner, 1966).

One of the best hardwoods for planting in pure stands on Kentucky spoils; failed when planted in a locust mixture (Merz and Boyce, 1948). Adaptable to wide range of spoil conditions; good survival, rapid height growth (Ibid.). Should not be planted on upper slopes or ungraded banks with coarse or loose soils in western Kentucky; best results at pH 4.0-8.0 (Carter et al., 1974). Fifty-three percent survival on eastern Kentucky spoils (pH 3.5-5.5, ungraded, silty clay shales) after 5 years; 30 percent when interplanted with European alder--average height of pure stand, 2.5 m (8.1 ft); interplanted, 3.8 m (12.4 ft) (Dale, 1963). Plass (1968) reported 80 percent survival, 0.9 m (3 ft) height after 4 years of plantings on sandstone and shale in eastern Kentucky spoils at pH 4.5-5.5.

Grew 1 year on kaolin spoils in Georgia; nitrogen and phosphorus needed (May et al., 1973).

Suitable for moist sites on Ohio spoils; grows well on mid-slopes (Limstrom and Merz, 1954; Finn, 1958). Successfully interplanted with black locust and other hardwoods in Ohio (Ibid.). Should not be planted on upper slopes of ungraded banks with coarse or loose soil (Carter et al., 1974). Eighty-eight percent survival after 22 years on Ohio spoils with coarse soil at pH 5.0-7.0 (Funk and Krause, 1965).

Midwestern Spoils

All species recommended for sands, loams and clays; growth on all slopes and graded banks at pH 6.0-7.5 (Limstrom, 1960). Successful results in large scale plantings in pure stands on spoils at pH 4.0-8.0 (*Ibid.*).

One of the best hardwoods for southern Illinois spoils at pH 4.5-8.0; suitable for silty clay spoils and areas where flooding does not exceed 1 week (Boyce and Neebe, 1959). Can be planted with sweetclover and low plants to form a sparse cover; should not be underplanted with black locust (*Ibid.*). Seventy percent survival on Illinois spoils (*Ibid.*).

Adaptable to dry Indiana site conditions; found on very rocky stripped lands; good results on acid loams and silty clays (Dietschman and Lane, 1952). Should not be planted under locust cover (*Ibid.*). Sixty-seven percent survival after 10 years on some Indiana spoils; 63 percent, 6.1 m (20 ft) height and 37 percent, 7.6 m (25 ft) height on others (DenUyl, 1962). Plant only on calcareous soil (*Ibid.*).

Can be planted in mixtures with black walnut on southeastern Kansas spoils of loose shaly clay at pH 7.5 (Seidel and Brinkman, 1962). Twenty-four percent survival, 11 m (37 ft) height after 22 years on nutrient-rich Kansas spoils of pH 5.6-6.1 (Geyer and Rogers, 1972). Eighty-two percent survival, 17 m (55 ft) height on ungraded Kansas and Missouri spoils, (63 percent soil, pH 5.5-7.0) after 20 years; 20 percent survival, 7.6 m (25 ft) height on graded spoils (Chapman, 1967). Clark (1954) reported 38 percent survival, 2.1, (7 ft) height after 5 years on spoils in Kansas, Missouri and Oklahoma. Moist sites produced good results; does not tolerate heavy cover. (*Ibid.*).

TAMARISK (Tamaria): French Tamarisk or Sultcedur - *Tamarix gallica*

Weed, invaded plantings of other species on Utah copper and uranium tailings (Nielson and Peterson, 1972). Salt and wind resistant, tolerates high pH and salinity (Graetz, 1973; Hodgson, 1973). Rated excellent when fertilized on saline-alkaline Arizona copper tailings (Ludeke, 1974).

TIMOTHY: *Phleum pratense*

Perennial. *Guide for Revegetating* (1965) reports timothy grows well on neutral spoils (pH 5.0 or greater) in Pennsylvania and on slopes less than 25 percent. It has been used as a nurse for white clover on northern Michigan mine tailings (Shetron and Duffek, 1970). Berg (1975) reports it is used to broadcast on steep slopes; small round seed catches in cracks of Colorado sub-alpine regions. Dies in 5-6 years at high elevations (*Ibid.*).

TOBIRA PITTOSPORUM: *Pittosporum tobira*

Evergreen shrub, salt and wind resistant (Graetz, 1973).

VIRGINIA PINE: *Pinus virginiana*

Tree with a short trunk found mainly in the north and southeastern United States (Sargent, 1933). More successful than Scotch or Australian pine, provided good cover and stability (Schimp, 1966). Recommended for sands or loose loams and clays at pH 4.5-6.0 in mixtures of 1 to 5 percent (Limstrom, 1960). Less growth than shortleaf, loblolly or pitch pine after 6 months on sandstone and shale spoils in laboratory tests (Plass, 1969).

Eastern Spoils

Well suited for planting on poorer, dry shale soils in the Northeast (U.S. Bureau of Mines, 1961).

Davis and Melton (1963) reported good results with plantings on the Pittsburgh seam only. Most acid tolerant of all conifers; plants have been found volunteering on spoils at pH 3.5 in Pennsylvania; slow growth rate, however, on highly acidic spoils (Miles *et al.*, 1973). Good vigor on slopes of 25 percent or less (*Guide for Revegetating*..., 1965). Fifty-six percent survival on graded Pennsylvania anthracite spoils at pH 4.0-7.0 after 5 years; 23 percent on ungraded spoils (Czapowskyj, 1970). Sixty percent survival, 1.7 m (5.7 ft) height after 7 years on anthracite spoils (Czapowskyj and Writer, 1966).

One of the better successes on Tennessee spoils; can be mixed with ryegrass and fertilizer for better production (Varger *et al.*, 1968).

Poor growth form, with many limbs extending to the ground, exhibited on plantings on western Kentucky spoils; susceptible to moth attack (Boyce and Merz, 1948). Carter et al. (1974) reported good results on Kentucky spoils at pH 4.0-7.5; should be planted in bands of 5 rows or in pure blocks. Ninety-three percent survival after 5 years at pH 3.5-5.5 (Dale, 1963).

Virginia pine is generally compatible with annual plants, but mouse gridling has been reported and deer browsing occurs on certain species (U.S. Bureau of Mines, 1961). Good results on poor sites; recommended for planting at elevations below 760 m (2500 ft) on poorest sites; good results on heavier textured clay soils (U.S. Bureau of Mines, Circular 109, 1960). Forty-eight and seven-tenth percent survival, good species for strip mined aras, low moisture and nutrient requirements, may suffer winter injury if planted above 760 m (2500 ft) (Brown, 1962; 1971). Ruffner (1966) reports that Virginia pine has widest range of adaptability on West Virginia spoils of the nine conifers tested; tolerates acidity as low as pH 4.0.

Midwestern Spoils

Good results on spoils of pH 4.0-7.5; subject to tipmoth (Crowl, 1962). Hardy species in northern Illinois plantings; best survival was on slopes, ridges and acid areas (pH 4.5-6.9) (Boyce and Neebe, 1959). Forty-five percent survival on Illinois spoils at pH 4.0 after 21 years; grading had little effect (Chapman, 1967). Twenty-one percent survival, 7.3 m (24 ft) height, after 22 years on nutrient-rich Kansas spoils at pH 5.6-6.1 (Geyer and Rogers, 1972).

WAGNER FLATPEA

Legume. Vigorous growth, tendency to vine, but seeds are poisonous to livestock (Ruffner, 1966). Adapted climatically throughout West Virginia; takes 2 to 3 years longer than crownvetch to form 100 percent cover; will tolerate a slighly more acid spoil than flatpea (Ibid).

WEEPING LOVEGRASS: Eragrostis curvula

Warm season, short-lived perennial, good seedling vigor, quick cover, tolerates acid spoils pH 4.0-5.0 (Ruffner and Steiner, 1973). Produces well on most well-drained soil types; excellent results and stabilization obtained on sandy loams soil (Dalrymple, 1968).

Produces comparatively well on low fertility soils; nutritious and palatable when fertilizer is applied regardless of inherent fertility of soil; excellent cover with legume (Ibid.).

Does well in different mixtures: forage legume-lovegrass--promising for forage and conservation; bermudagrass-lovegrass--also good results; alfalfa-lovegrass--suitable for hay, winter grazing and conservation (Ibid.). Ermelo weeping lovegrass has been used for nematode control in tobacco cordons of Africa; recommended for permanent cordons in Brazil coffee, cotton and tobacco (Ibid.). Schellie and Rogier (1973) observed that weeping lovegrass needs 15-20 inches of precipitation per year.

Eastern Spoils

Provides quick cover on Kentucky spoils; adaptable to wide range of spoil conditions (Vogel, 1964). Weeping lovegrass was found to spread onto adjacent barren areas by natural seeding from established plants, but it is not an aggressive spreader and does not pose a threat as a potential weed in cultivated land (Ibid.). Vogel and Berg (1968) reported that weeping lovegrass provided 70-90 percent ground cover in one season on highly toxic spoils (pH 4.0-4.5) when fertilized consistently. Better adaptation to drier sites and summer conditions (Ibid.). Carter et al. (1974) obtained good results on western Kentucky spoils (pH 4.0-8.0) in a mixture with Ky 31 and sericea (0.3 g/m^2) (3 lbs per acre) when planted in spring. In mixtures with tall fescue, rye or hybrid sorghum it has one of the best high temperature germination rates (Revegetation, 1966).

On West Virginia spoils, it gives quickest cover (Ruffner, 1966). Reseeds well on spoils with pH of 5.4; cover decreases at pH 5.5 or higher--salt sensitive (Ibid., Revegetation, 1966). Capp and Gillmore (1974) reported little success after first year of growth on West Virginia acid spoils even after addition of fly ash and fertilizer.

Mineral Tailings

Fleming et al. (1974) reported laboratory test results showed that lovegrass tolerates pH 4.0; manganese (964 ppm), and aluminum (12 ppm) are harmful to growth, but lovegrass is more tolerant to aluminum than tall fescue. Tolerates spoils of pH 2.0-3.0 when overlaid with 5 cm (2 inches) sewage effluent and 5 cm (2 inches) sludge per week for 11 weeks (Sopper et al., 1974). Good response obtained in mixtures with Blackwell switchgrass, deertongue or reed canarygrass. Craig (1975) found giant lovegrass very slow to establish on tailing sands of Florida phosphate mines. Mice killed the lovegrass and spread began to decline after 3 years on Japanese copper mines (Usiu and Suzuki, 1973). Beverly (1970) reported excellent results on Arkansas vanadium tailings in one year without fertilizer (150 cm (60 inches) precipitation per year, long growing season). Used in mixture on gold mine tailings in South Africa (Stabilizing Mine Dumps, 1968). Successful for 5 years on South African gold mine tailings which were limed and fertilized (Cresswell, 1973).

WHEAT: Winter - *Triticum aestivum* or *Triticum vulgare*

Annual (Hitchcock, 1935).

Eastern Spoils

Good on spoils with pH 4.5 or greater (*Revegetation Manual*, 1966). Quick cover, less competitive with peremanent species than rye (Carter *et al*., 1974).

Mineral Tailings

Winter wheat promosing on Southwest tailings (Dean *et al*., 1971). Nielson and Peterson (1972) reported 90 percent germination on leached, copper mine tailings of Utah. Fifty-two percent germination after one month when planted in September, fertilized and sprayed with Coherex on high altitude tailings, 2000 m (6500 ft) and with 21 cm (8.3 inches) of precipitation per year (Shirts *et al*., 1974). These results are better than for other grasses or legumes (*Ibid*.).

WHEATGRASS: *Agropyron sp.*:

Sodar or Streambank - *A. riparium*
Slender - *A. trachycaulum*
Pubescent - *A. trichophorum*
Western - *A. smithii*
Bluebunch - *A. spicatum*
Intermediate - *A. intermedium*
Thickspike - *A. dasystachyum*
Siberian - *A. sibiricum*
Crested - *A. desortorum*
Crested (fairways) - *A. cristatum*
Tall - *A. elongatum*
Bearded - *A. subsecundum*

Perennials, often with creeping rhizomes; most furnish forage and a few are among the most valuable range species in Western States (Radford, 1968; Hitchcock, 1935). Tresler (1975) observed that thickspike is rhizomatous, well adapted to low precipitation areas, 25-36 cm (10-14 inches) rainfall per year and sandy soils; Western (Rosana) is rhizomatous, good for heavier-textured soils; Beardless (Whitmar) is a bunchgrass, good for dry soils. Bluebunch is a bunchgrass, excellent results in coarse soils in areas with 25-36 cm (10-14 inches) of precipitation per year and in loam soils (*Ibid.*). Streambank (Sodar) is rhizomatous, good results in dry areas, loam and sand; Pubescent--rhizomatous--good in spoil areas with greater than 36 cm (14 inches) of precipitation per year and is a good pasture and hay producer (*Ibid.*). Crested is a bunchgrass, early spring forage and produces well in normal soils with greater than 25 cm (10 inches) of rainfall per year (*Ibid.*). Intermediate (Tegmar) is a short-lived rhizomatous plant (*Ibid.*).

Eastern Spoils

Intermediate wheatgrass produced good results on West Virginia acid spoils that were neturalized with the addition of fly ash (Capp and Gillmore, 1974). Ruffner (1966) reported that crested wheatgrass produced a good stand on fertilized plots at pH 5.5; stand still fair to good after 4 years, but some reseeding was needed to maintain stand. Cover is poor compared to fescue (*Ibid.*). Intermediate wheatgrass also produced a good stand on fertilized West Virginia spoils at pH 5.5 (*Ibid.*).

Western Spoils

Western wheatgrass produced excellent yield on Colorado spoils; well adapted to different types of ranges (Merkel *et al.*, 1973). Produced sufficient amount of herbage on spoils with good soil, 42 cm (16.4 inches) of precipitation per year and 50 percent snowfall (*Ibid.*). Bearded bluebunch and Griffiths wheatgrass performed sufficiently well at the Meeker planting; litter production adequate (*Ibid.*). On Colorado spoils, crested wheatgrass gave good litter on soils at pH 8.4; intermediate produced excellent results but provided little cover; pubescent gave excellent stands, aids in soil erosion control (*Ibid.*).

Berg (1975) reported that slender wheatgrass is no good at the high elevations of the Colorado subalpine regions, dies in 4-5 years. Intermediate adapted to drier sites in the lower subalpine regions; pubescent is similar to intermediate, except that it is less palatable, and more spreading; streambank produced fair vigor, lower growth than intermediate; western, hard to establish, produced results like intermediate (Ibid.).

Black and Siddoway (1971) reported that tall wheatgrass served as an excellent barrier for soil erosion control and reduced wind velocites on plantings on the Great Plains.

Different species of wheatgrass produced fair to good results on coarse Montana spoils at pH 7.5-8.5, graded topsoil and 25-36 cm (10-14 inches) of precipitation per year (Thornburg, 1975). Crested good for dry soils, poor for wet soils; intermediate generally poor results; pubescent good for dry soils, poor for wet and saline-alkaline spoils; Siberian good for dry soils and steep slopes, poor results on wet soils; slender fair to poor results; streambank good for dry soils and steep slopes, poor for wet soils; tall good for saline-alkaline spoils, poor for steep slopes; thickspike good for dry, steep slopes, poor for wet soils; western good for wet, saline-alkaline spoils (Ibid.). Buchholz (1972) reported that wheatgrass on Montana spoils also needs nitrogen and phosphorus additives.

In greenhouse testings in Wyoming, crested and western gave best germination percentage; western better adapted than inland saltgrass; intermediate and crested are good cool season grasses, produced better results with the addition of mulching (May et al., 1971).

Alkar tall wheatgrass tolerates high salinity, grew in leached spent shale--best of the species tested on oil shale spoils (Schmehl and McCaslin, 1973; Cook, 1974).

Mineral Tailings

Slender wheatgrass exceptionally vigorous and produced seed in first growing season on Utah mineral tailings (Farmer et al., 1974). Wheatgrass dominated in dry-weight production in each seed mixture tested (Ibid.). Shirts (1975) reported that a mixture of crested and clover produced the best results on Utah uranium tailings at 2000 m

(6500 ft) elevation with pH 8.0 and fertilizer added. Tall wheatgrass best for leached copper tailings in Utah; intermediate, Siberian, sodar and crested wheatgrass also good (Nielson and Peterson, 1972; Dean et al., 1971; 1974).

Tall and crested in a mixture with Regar brome and tall fescue produced good results after 3 months on Washington copper tailings at pH 2.6-3.5, 978 m (3209 ft) elevation and 76 cm (30 inches) of precipitation per year (Shirts et al., 1974). Siberian wheatgrass produced 95 percent germination in laboratory tests on uranium tailings at pH 2.7 that were neutralized with lime and sludge (Ibid.). Tall and Siberian produced 15 week survival and high germination on neutralized Washington and Colorado tailings, failed on highly saline Arizona berm tailings (Ibid.).

Beverly (1970) reported excellent results with a mixture of tall and crested wheatgrass and sand dropseed on Colorado uranium tailings that were covered with soil and irrigated (25 cm (10 inches)) of precipitation per year). Irrigation is essential; applications of manure is also helpful; mixtures of tall fescue and tall wheatgrass also proved success-ful (Ibid.).

Crested wheatgrass produced fair results on saline Nevada copper tailings that were pelletized and mixed with sewage sludge (Dean and Havens, 1973).

WHITE PINE: Pinus strobus

Tree, forming nearly pure forests on sandy drift soils, or, more often, small groves (Sargent, 1933).

Eastern Spoils

Versatile as to site but influenced by infertility, frost pockets and poor drainage; adaptable to wide range of spoils; weevil or blister rust may damage species (U.S. Bureau of Mines, 1961).

White pine did well on spoils of the Brookville and Pittsburgh coal seams but very slow growth on the spoils of the Lower and Middle Kittanning seams (Davis and Melton, 1963). Failed to establish when direct seeding was used (Miles et al, 1973). Seventy-three percent survival on Pennsylvania spoils with pH above 4.5; thirty-three percent on spoils at pH below 3.5 (Magnuson and Kimball, 1969). Best results on spoils above pH 5.0 and slopes of 25 percent or less (Guide for Revegetating..., 1965). Thirty-nine percent survival on Pennsylvania bituminous spoils after 10 years; heavily infested with White pine weevil; bad results on exposed ridge tops (Hart and Byrnes, 1960). Good results on Pennsylvania spoils at pH 2.0-3.0 when overlaid with 5 cm (2 inches) municipal sewage effluent (Dickerson, 1971). Sixty-three percent survival after 5 years on graded Pennsylvania anthracite spoils (pH 4.0-7.0); 20 percent on ungraded spoils (Czapowskyj, 1970). Sixty-four percent survival 0.8 m (2.5 ft) height after 7 years on Pennsylvania anthracite spoils (Czapowskyj and McQuilken, 1966). Sopper et al. (1975) reported 80 percent survival in laboratory tests on anthracite refuse at pH 3.0; sludge treatment brings survival up to 100 percent.

Generally reported to be compatible with sod and annual plants on Allegheny spoils, also compatible with light brush. Damaged by deer browsing but little rabbit clipping (U.S. Bureau of Mines, 1961).

Best adapted conifer for growing in climate of West Virginia; less initial vigor than Virginia, shortleaf, Scotch or red--good stand once established (Ruffner, 1966; Mellinger et al., 1966; Brown, 1962). Sixty-eight and six-tenth percent survival on West Virginia spoils (Brown, 1962). Brown (1971) reports white pine adaptable to wide range of spoils; good growth, can be used for sawlogs and pulpwood. Best growth on deep loamy, well drained soils; very susceptible to blister rust and white pine weevil (USBM, Circular 109, 1960).

Slow growth the first 3-5 years on eastern Kentucky spoils (Revegetation Manual, 1965). Should not be used with a nurse species or planted on graded banks with firm, fine soils (Carter et al., 1974).

Should not be planted with black locust or other species that would overtop it on Ohio spoils; should be confined to relatively coarse-textured strip mine sites having a high percentage of soil; does not produce good results on calcareous, fine textured land material (Finn, 1958). Limstrom and Merz (1954) suggest that plantings be limited to spoils with loamy or sandy soils; plant in pure stands or with other conifers. Sixty-four percent survival on unfertilized loose, shaly Ohio spoils of pH 5.5-7.0; 24 percent survival on fertilized spoils (Funk and Krause, 1965). Lowry (1960) reported average 2 year survival and growth on sandy, loamy, or silty clay Ohio spoils with varying pH.

Midwestern Spoils

Recommended for compact loams and clays at pH 4.0-7.5 (Crowl, 1962). Light to heavy cover at pH 4.5-6.0; good results on sandy soils also (Limstrom, 1960).

Poor growth on Illinois spoils; survival and height good on acidic, ungraded, southern Illinois spoils (Boyce and Neebe, 1959). Forty percent survival, 12 m (40 ft) height after 21 years on ungraded Illinois spoils with pH 5.0, 40 percent soil (39 percent of which was clay); complete failure on graded soils (Chapman, 1967).

Mineral Tailings

Good results on dark sand with high fertility on northern Mighican mine tailings and dunes (Goldfinger, 1971).

WILDRYE: (See Rye)

WILLOW: Tall, Purple Osier - Salix purpurea

Trees or shrubs with watery juice (Sargent, 1933). Pioneer specie on West Virginia gob piles (Coalgate, 1973). Ruffner (1965) reports good results on bituminous Ohio spoils with pH 5.0 or greater and excellent results with pH 6.0 or greater. Good results on wet soils in Montana at pH 7.5-8.5 (Thornburg, 1975).

YUCCA: Yuccae

Tree found from Bermuda and the eastern Antilles through the south Atlantic and Gulf States to Oklahoma and Arkansas, and through New Mexico and northward along the eastern base of the Rocky Mountains to South Dakota, westward to middle California, and southward through Arizona, Mexico and lower California to Central America (Sargent, 1933). Promising for dune areas (Graetz, 1973). High survival rates on all spoils in Pennsylvania, good adaptability and provides good surface cover (Schimp, 1966). Grows well in poor soil; drought resistant (How Green are Our Valleys, 1968).

APPENDIX C

LISTING OF DIRECTORS OF STATE AGRICULTURAL EXPERIMENT STATIONS, INSTITUTES AND CENTERS; REGIONAL CONTACTS (CSRS-OD-1020, July 1975)

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WASHINGTON, D.C. 20250
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